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(54) Title: MODIFICATION OF CLOSTRIDIAL TOXINS FOR USE AS TRANSPORT PROTEINS

(57) Abstract

A chemical conjugate for treating a nerve cell related disorder is provided. This conjugate includes an active or inactive Clostridial toxin having specificity for a target nerve cell. The toxin is conjugated to a drug or other bioactive molecule without affecting the toxin's ability to enter the target nerve cell.

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MODIFICATION OF CLOSTRIDIAL TOXINS FOR USE AS TRANSPORT PROTEINS

Field of the Invention

The present invention relates generally to the field of receptor-targeted biochemical delivery systems. More specifically, this invention relates to the use of modified polypeptide toxins as vehicles for delivering chemical compounds to cells bearing toxin receptors.

Background of the Invention

Tetanus toxin (TeTx) and botulinum toxin (BoNT) are potent neurotoxins that induce paralysis by mechanisms that involve the inhibition of neurotransmitter release. Th se *Clostridial* neurotoxins are initially produced as single-chain proteins of ~150 kDa. Proteolytic cleavage then generates an active dichain molecule having a ~100 kDa heavy (H) and a ~50 kDa light (L) chain that are linked by a single interchain disulfide bond. The H chain contains domains which contribute to the binding of the toxin to neuronal cell surface receptors and which facilitate translocation of the L chain into cells. The L chain is responsible for blocking neurotransmitter release.

The mechanisms of toxin action have recently been clarified. The TeTx-L chain is a zinc-dependent protease specific for the vesicle-associated protein called synaptobrevin or vesicle-associated membrane protein (VAMP). The cleavage of VAMP by the TeTx-L chain inhibits neurotransmitter release by preventing the docking/fusion of transmitter-containing vesicles and the presynaptic membrane.

While a single isoform of TeTx is produced by *Clostridium tetani*, seven serologically distinct isoforms of BoNT are produced by *Clostridia botulinum*. These seven botulinum toxin species are designated as BoNT/A-G. Like tetanus toxin, the botulinum type B neurotoxin is a zinc-dependent protease. In *EMBO J.* 12:4821 (1993), Blasi et al. proposed that the botulinum neurotoxin serotypes have evolved distinct substrate specificities while retaining a common protease activity. Botulinum neurotoxins B, D, F and G also cleave VAMP or a closely related isoform. In contrast, BoNT/A and BoNT/E cleave a synaptosome associated protein of molecular weight 25 kDa (SNAP-25). Finally, BoNT/C has been shown to cleave syntaxin. In addition to these target proteins, TeTx and BoNT/B have been reported to cleave Cellubrevin. Thus, the intraneuronal targets of the *Clostridial* toxins universally participate in the process of neurotransmitter release.

All of the *Clostridial* neurotoxins apparently bind different cell surface receptors and proteolyze cellular components that are required for neurotransmitter release. TeTx exerts

its effect in the spinal cord and lower brain stem by reducing the activity of inhibitory neurons. The seven isoforms of BoNT all produce a flaccid paralysis. Mechanistically, the botulinum toxins selectively inhibit peripheral cholinergic nerve terminals which are predominantly found at neuromuscular junctions.

Certain zinc-dependent endoproteases contain the conserved amino acid sequence HExxH. In thermolysin, zinc binding is achieved via His^{142} and His^{146} within this motif, together with Glu^{166}; the fourth ligand is water. Comparison of tetanus L chain with thermolysin and other zinc endoproteases revealed the presence of the same consensus motif. Conceivably then, Glu^{234} of TeTx-L chain might correspond to the critical Glu^{145} residue in thermolysin.

The role of Glu^{234} within this motif in the L chain of TeTx has been studied using site-directed mutagenesis and an *in vitro* assay for the proteolysis of cellubrevin. In *Nature* 364:346 (1993), McMahon et al. demonstrated that cellubrevin was not cleaved when COS cells were cotransfected with mutant L chain (Glu^{234} substituted by Gln) and cellubrevin DNA constructs.

Summary of the Invention

One aspect of the present invention relates to a chemical conjugate for treating a nerve cell related disorder. This conjugate includes an active or inactive botulinum or tetanus toxin having specificity for a target nerve cell. The toxin is conjugated to a drug or other bioactive molecule without affecting the toxin's ability to enter the target nerve cell. Thus, one aspect of the present invention relates to a chemical conjugate for treating a nerve cell related disorder. The chemical conjugate includes an inactive Clostridial neurotoxin having specificity for a target nerve cell, and a drug or other bioactive molecule attached to the neurotoxin. The neurotoxin retains its ability to enter the target nerve cell. The Clostridial neurotoxin can be any of a variety of such toxins, including tetanus toxin, botulinum toxin A, botulinum toxin B, botulinum toxin C, botulinum toxin D, botulinum toxin E, botulinum toxin F and botulinum toxin G. Inactivation of the Clostridial neurotoxin can be accomplished by an amino acid change in its light chain. Thus, for example, the inactivated Clostridial neurotoxin can be tetanus toxin having a modification of Glu^{234}, a botulinum toxin A having a modification at His^{227} and/or Glu^{224}, or a botulinum toxin other than botulinum toxin A having a modification at a site corresponding to His^{227} and/or Glu^{224} of botulinum toxin A.

Another aspect of the invention involves the chemical conjugate as described above, for use in the treatment of a neuromuscular dysfunction in a mammal, such as a dysfunction relating to uncontrollable muscle spasms.

The invention also includes the use of the chemical conjugate described above in the preparation of a medicament for treatment of a neuromuscular dysfunction, such as a dysfunction relating to uncontrollable muscle spasms in a mammal.

In a particular aspect of the invention, the drug in the chemical conjugate is an active ingredient for treatment of botulism or tetanus. This aspect of the invention can be used to treat botulism or tetanus in a mammal, and can thus be used in the preparation of a medicament for such treatment.

Another aspect of the invention relates to the use of an inactive Clostridial neurotoxin in the preparation of a medicament for treatment of botulinum toxin poisoning. In this aspect, the inactive Clostridial neurotoxin can be used alone without conjugation to another drug.

An additional aspect of the present relates to the use of of chemical conjugate that includes an active clostridial neurotoxin and a drug. Such a conjugate is used in the preparation of a medicament for treatment of focal dystonias, spasticities due to stroke or traumatic brain or spinal cord injury, blepharospasm, strabismus, cerebral palsy or back pain due to muscle spasms.

In still another aspect, the invention relates to a method of treating a neuromuscular dysfunction in a mammal. This method includes the steps of preparing a pharmaceutically active solution which includes a Clostridial neurotoxin linked to a drug, and introducing an effective quantity of the pharmaceutically active solution into a mammal. The neurotoxin can be any of a variety of such toxins, including tetanus toxin, botulinum toxin A, botulinum toxin B, botulinum toxin C, botulinum toxin D, botulinum toxin E, botulinum toxin F and botulinum toxin G. The neurotoxin can be inactivated by an amino acid change in its light chain. In one embodiment, the drug inhibits neurotransmitter release, and in another the drug inhibits the activity of synaptobrevin. In a preferred application of the method, the method is used to treat a neuromuscular dysfunction relating to uncontrollable muscle spasms.

Further aspects of the present invention will be apparent to one having ordinary skill in the art upon reference to the ensuing detailed description.

Brief Description of the Figures

Figure 1 is a schematic representation of the TeTx and the DNA construct (pMAL-LC) used to express the MBP-L chain fusion proteins. The single-letter code in the first part of the figure represents the amino acid sequence of the first several residues of the purified recombinant L chain and Ala ^{234}-L chain determined by N-terminal microsequencing. The second part of the figure shows the H chain is disulfide bonded to the L chain. The location of the zinc-binding domain is also diagrammed.

Figure 2 is a graph showing the percentage of HV62 peptide (a synthetic fragment of human VAMP) cleaved by native, recombinant or mutant L chains as a function of time. The different symbols represent 33 (○), 100 (□) and 250 nM (▲) of native L chain; or 250 nM recombinant L chain (△); or 2.5 μM Ala^{234}-L chain (■). The inset shows the ability of Ala^{234}-L chain to reduce the apparent hydrolysis of HV62 substrate by native L chain. The open bar represents the % substrate hydrolyzed by native L chain in the presence of Ala^{234}-L chain, while the hatched bar represents % substrate hydrolyzed in the absence of Ala ^{234}-L chain.

Figure 3 shows a graph representing muscle tension (as % of an initial value) as a function of time as an assay of neuromuscular transmission. The different symbols represent 10 nM TeTx (○), 10 nM reconstituted native H chain and L chain (□), 10 nM recombinant L chain assembled with native H chain (△), 100 nM Ala ^{234}-L chain refolded with H chain (■). Values are the means (± SD) obtained from 3 experiments. The inset shows the results obtained with 20 nM reconstituted native H chain and L chain (□) and 40 nM reconstituted native H chain and recombinant L chain (△). Note that the stated concentrations of reconstituted samples have not taken into account the minor content of noncovalently linked chains.

Figure 4 is a schematic representation of the chemical synthetic scheme used to link the transporter protein and a drug molecule.

Figure 5 is a schematic representation of the recombinant BoNT/A light chain expression construct, pCAL. This was produced by insertion of the L chain gene between the BamHI and SalI restriction sites at the polylinker of the vector pMAL-c2. The vector contains the inducible P_{tac} promoter positioned to transcribe the *malE-LacZα* gene fusion. The *lacI^q* gene encodes the lac repressor which represses transcription from P_{tac} until induction by isopropyl β-D-thiogalactoside (IPTG). The *rrnB* terminator prevents transcription from interfering with plasmid replication. Amp^r encodes β-lactamase for ampicillin resistance.

M13-ori and pBR322ori indicate the origins of DNA replication. The Factor X_a cleavage site and L chain start ar denoted by arrows.

Figure 6 shows the recombinant SNAP-25 substrate for BoNT/A and presents graphic results from a cleavage assay developed by Western blotting. (A) Schematic representation of the C-terminal fragment of SNAP-25 encompassing the BoNT/A cleavage site, against which a polyclonal antibody was raised. (B) Graph of the numerical values obtained from densitometric scanning of Western blots. Reduced native BoNT/A (●) and recombinant wild-type L-chain (○) effectively cleaved SNAP-25, while the Tyr^{227} mutant was devoid of proteolytic activity (▽).

Figures 7A and 7B are line graphs illustrating that recombinant L chain or its fusion protein inhibit catecholamine release from permeabilized chromaffin cells. Figure 7A is before factor X_a cleavage and Figure 7B is after Factor X_a cleavage. Cells were permeabilized by incubation for 15 minutes with 20 μM digitonin in KGEP buffer (139 mM K^+glutamate, 5 mM ethylene glycol-bis[β-aminoethyl ether] N,N,N',N'-tetraacetic acid [EGTA], 2 mM ATP, 2 mM $MgCl_2$, 20 mM piperazine-N,N'-bis-[2-ethanesulfonic acid] [PIPES] pH 6.5) containing the indicated concentration of native BoNT/A (○; △) or recombinant L chain fusion protein before (●) or after (▲) cleavage with Factor X_a. Following a brief rinse with KGEP, cells were incubated for 15 minutes with KGEP with or without 20 μM free Ca^{2+}. An aliquot was then removed from each well and assayed for catecholamine content by a fluorometric method. Catecholamine remaining inside cells was calculated after Tx-100 solubilization, and secretion was calculated as a percentage of the total cell content (= remaining + released). Catecholamine in the Ca^{2+}-free buffer was subtracted from that secreted into that containing 20 μM Ca^{2+} to calculate evoked release.

Figure 8 is a line graph showing the effect of purified native and recombinant wild-type and mutant L chain on nerve-evoked neuromuscular transmission at motor end plates following reconstitution with the native H chain of BoNT/A. When applied to mouse phrenic nerve-hemidiaphrams, BoNT/A H chain reconstituted with recombinant L chain (1.6 nM; ○) blocked neuromuscular transmission with approximately the same efficacy as the native reconstituted L and H chains (2.0 nM; ▽). In contrast, even a larger amount of the dichain containing the Tyr^{227} mutant form of the L chain (10 nM; ●) was incapable of affecting nerve-evoked muscle twitch. The concentrations of the reconstituted material were calculated following the quantification of the amount of the 150 kDa dichain material present by SDS-PAGE and densitometric scanning. The tissues were bathed in Krebs-Ringer medium

aerated with 95% O_2 and 5% CO_2 maintained at 24°C. All points shown are the average of at least three separate experiments ± SD.

Figure 9 is a schematic representation of the constructs used to produce MBP-BoNT/A-L chain double mutant ("1") and MBP-TeTx truncated L chain-BoNT/A-L chain double mutant ("2").

Detailed Description of the Invention

The present invention relates to the use of modified *Clostridial* neurotoxins, in their dichain forms, as transporters for the delivery of linked pharmacologic compounds. Among the compounds that can be linked to the toxin transporters are visualizable agents bearing fluorochromes, and drugs of therapeutic value. Whereas the enzymatic properties of the native toxins could be a disadvantage in such applications, we have discovered a means for overcoming this limitation. The contemplated cell populations that are targeted by the toxin transporters include those which express cognate toxin receptors.

We discovered that an effective drug delivery agent can be prepared by mutating one or more amino acid positions in the L chain of a *Clostridial* neurotoxin, to inactivate its protease activity, and then attaching a drug to that inactivated neurotoxin. Despite this abolition of enzymatic activity, the mutagenized toxin advantageously retained the ability to bind its cognate cell surface receptor. In addition, we have discovered other unexpected properties of the attenuated *Clostridial* toxins.

Significantly, we have discovered that both the heavy and L chains of the *Clostridial* neurotoxins are required for optimal receptor-ligand interaction. In light of this finding, we reasoned that a toxin transporter would advantageously comprise both chains of the dichain molecule. Since the toxic properties associated with the L chain molecule could interfere with the therapeutic effect of a drug that was covalently linked to the transporter, we created an attenuated L chain molecule that was reconstituted with native H chain; the ability of the resultant dichain molecule to bind to the cognate receptor and undergo internalization was retained. We discovered this could be accomplished, with apparently minimal disruption to the folded structure of the L chain protein, by mutation of one or more amino acid positions.

Accordingly, use of the inactivated *Clostridial* toxin as a vehicle that can be covalently linked to a drug has been explored. Reconstituted toxin, having an inactivated L chain disulfide-bonded to a native H chain, retained the ability to specifically interact with target receptors and become transported to the cytosol, together with the attached molecule.

Hence, the inactivated and chemically modified toxin complex can be used as a system for delivering linked chemical compounds t the cytosol of neuronal cells that express cell surface r ceptors for the toxins.

In the development of the present invention, the gene encoding TeTx-L chain was modified at the 5′ end by the addition of a DNA sequence encoding a maltose-binding domain. This domain, therefore, was added to the N-terminal portion of the TeTx-L chain protein. Following expression in *E. coli*, the recombinant fusion protein (called MBP-L chain) was purified by affinity chromatography. Proteolysis by factor X_a allowed separation of the L chain and the MBP domains of the fusion protein. The purified L chain was then combined with purified H chain that had been isolated from *C. tetani*- derived TeTx to generate a dichain. This reconstituted TeTx molecule displayed activities characteristic of the native toxin. Parallel findings have also been made using the recombinant BoNT/A- L chain protein after reassociation with native BoNT/A-H chain protein.

In other experiments, modification of Glu^{234} to Ala in the TeTx-L chain abolished its ability to cleave VAMP or a synthetic substrate that contained the cleavage recognition site for TeTx-L chain. Advantageously, neurotoxicity of the complex formed by the mutant L chain and a wild-type H chain was also abolished, although the modified toxin retained th ability to bind its receptor. In a similar experiment, separate BoNT/A-L chain molecules were modified at either the His^{227} or Glu^{224} or both residues. These modifications in the BoNT/A-L chain caused the loss of proteolytic activity against cellular target substrates.

Since many individuals are immunized against tetanus toxin, it is believed advantageous to further modify the TeTx molecule so that it will be minimally neutralized by circulating antibodies. Modifications to the TeTx molecule that retain its cellular binding and internalization ability, but limit its detection by the immune system are preferred.

By the methods described herein, mutant *Clostridial* toxins can be synthesized; moreover, they retained the ability to be effectively internalized and transported to the cytosol.. These toxins advantageously retain the ability to bind neurons, even in the absence of an associated protease activity. These attenuated toxins are useful in the production of novel systems for the specific delivery of chemical agents to target neurons.

The mutagenized and enzymatically inactive dichain *Clostridial* toxins described herein can advantageously serve as neuropharmacologic agents for transporting chemical compounds to neuronal cells that express cell surface receptors for the toxins. Bonding of chemical agents to the transporter protein is requisite for practice f the invention. Such

ch mical ag nts can be pharmacologic agents, chemotherapeutic agents or visualizable agents that can be detected by light or other form of electromagnetic radiation.

Despite a number of similarities, those of ordinary skill in the art will appreciate that tetanus and botulinum toxins are functionally distinct in at least one important respect. Tetanus toxin is taken up by motor neurons and then transported to the spinal cord where it produces spasticity with convulsions. Thus, Tetx can reach target cells in the spinal cord by a pathway that begins in the muscles and traces back to the spinal cord. Conversely, the various BoNT serotypes all exert localized neurotoxicity at cholinergic nerve terminals, substantially confined to the site of injection.

This difference between the ability of TeTx to transit to the spinal cord and exert toxic activity and the localized activity of BoNT can be exploited in therapeutic protocols employing modified toxin-transporters. In particular, modified toxins based on TeTx are expected to carry linked drugs to the spinal cord along a neural pathway that connects the spinal cord and the injected muscle. Conversely, modified toxins based on one of the botulinum serotypes are expected to remain localized at the site of injection. Hence, a clinician using therapeutic agents based on the modified toxin-transporters of the following invention can selectively deliver drugs to the region of the spinal cord by injecting a TeTx-based therapeutic agent into an appropriate muscle. Alternatively, administration of a BoNT-based therapeutic agent into a muscle is expected to exert activity confined to the motor neurons at the site of injection.

The inactive tetanus toxin transporter can be primarily used to deliver drugs to target tissues for the purpose of controlling spasticity and excess movements in general areas, such as an arm, leg or portion of the body. The drug and transporter can be administered intramuscularly in one or more muscle groups which originate from the spinal cord target. In general, diseases affecting muscles below the neck are ideal targets.

Diseases that are believed to be benefited from such therapies include, but are not limited to, spasmodic torticollis, post stroke or traumatic brain injury induced spasticity, and dystonias of large muscle groups.

The inactive botulinum toxin transporter can be primarily used to deliver drugs that target the peripheral motor nerve terminal. Therefore, diseases which affect limited muscle groups can be most appropriately treated using the BoNT/A based transporter. Transporters based on other botulinum toxin s rotypes are also believed effective for this purpose.

Table 1

Therapeutic Uses of *Clostridial* Toxin Transporters

Transporter Molecule	Tissue Target	Drug Type	Mechanism of Action	Possible Clinical Outcome
Inactive-intact-tetanus toxin	Spinal cord	GABA agonist	Increase inhibitory neuron activity.	Block spasticity or cause a group of muscles to relax (at cord level), based on muscles injected.
Inactive-intact-tetanus toxin	Spinal cord	Neuronal Calcium Channel Agonist	Increase nerve firing of inhibitory neurons of the spinal cord.	Block spasticity or cause a group of muscles to relax (at cord level), based on muscles injected.
Inactive-intact-tetanus toxin	Spinal cord	Adenosine agonist	Reduce firing of interneurons at the spinal cord.	Block spasticity or cause a group of muscles to relax (at cord level), based on muscles injected.
Inactive-intact-tetanus toxin	Spinal cord	Glutamate antagonist (or other EAA antagonist)	Reduce firing of interneurons at the spinal cord.	Block spasticity or cause a group of muscles to relax (at cord level), based on muscles injected.
Inactive-intact-tetanus toxin or Active toxin	Spinal cord	Ricin or other protein synthesis toxins	Selective destruction of motor neurons in spinal cord.	Permanent paralysis.
Inactive-intact tetanus toxin	Spinal cord	Captopril and other zinc dependent protease inhibitors, including specially designed inhibitors of enzyme and other activities of tetanus toxin	Block proteolytic and other actions of the toxin.	Such transporters could be used in the treatment of tetanus when linked appropriately to effective drugs.

Transporter Molecule	Tissue Target	Drug Type	Mechanism of Action	Possible Clinical Outcome
Inactive-intact tetanus toxin	Spinal cord	Neuronal growth factor (GF) or GF gene and activation promotor	Stimulate growth of neurons.	Treatment of neurodegenerative disease (i.e., ALS, etc.)
Inactive-intact tetanus toxin	Spinal cord	Antiviral medication or gene therapy	Block viral replication	Prevent viral related neurodegeneration.
Inactive-reduced/ alkylated-botulinum toxin	Peripheral skeletal muscle targeted by injection	Nicotinic antagonist	Binds to ecto-acceptors on motor nerve endings but is not internalized efficiently; the drug could be attached which is released by local acetylcholine esterase. This drug would then block the AChR on the muscle, released from the depot in the synapse.	Prolonged skeletal muscle weakness, reduction of spasticity and/or pain. Duration: hours to several days
Inactive-reduced/ alkylated-botulinum toxin or Active intact	Peripheral skeletal muscle targeted by injection	Neuronal calcium channel blocker	Block calcium entry into neuron and thus prevent release of transmitter. Binds to ectoreceptor and released as above.	Prolonged skeletal muscle weakness, reduction of spasticity and/or pain. Duration: hours to several days
Inactive-reduced/ alkylated-botulinum toxin	Peripheral skeletal muscle targeted by injection	Acetylcholine esterase inhibitors	Binds to ecto-acceptors on motor nerve endings but is not internalized efficiently. The drug released locally by hydrolysis and blocks acetylcholine esterase.	Enhanced muscle contraction. Could counter the effect of Botox and be used in the treatment of myasthenia gravis.
Inactive-intact botulinum toxin or Inactive-reduced/ alkylated	Peripheral skeletal muscle targeted by injection	K^+ channel activator	Activate K^+ channel and thus reduce Ca^{++} flow	Muscle weakness
Inactive-intact-botulinum toxin	Peripheral skeletal muscle targeted by injection	Vesamicol or analog	Block transport of acetylcholine into the vesicle in the nerve terminal.	Prolonged skeletal muscle weakness, reduction of spasticity and/or pain. Duration: hours to several days

Transporter Molecule	Tissue Target	Drug Type	Mechanism of Action	Possible Clinical Outcome
Active-intact-botulinum toxin	Peripheral skeletal muscle targeted by injection	Ribozyme or oligonucleotide	Same target mRNA as inactive transporter, above.	Prolonged skeletal muscle weakness or flaccidity, reduction of spasticity and/or pain. Duration: > 3 months
Inactive-intact-botulinum toxin	Peripheral skeletal muscle targeted by injection	Captopril and other zinc dependent protease inhibitors, including specially designed inhibitors of enzyme activities or other actions of botulinum toxin serotypes.	Block proteolytic and other actions of the toxins.	Antagonize the effect of a Botox injection, if administered early enough. In particular, such transporters could be used in the treatment of botulism caused by the various toxin serotypes when linked appropriately to effective drugs.
Inactive-intact botulinum toxin	Peripheral nerves and ganglion	Antiviral medication or gene therapy	Block viral replication	Prevent viral related neurodegeneration and ulcers/cold sores.
Inactive-intact-botulinum toxin	Peripheral skeletal muscle targeted by injection	Ribozyme or oligonucleotide	Prevent synthesis of critical nerve component needed for the neural transmitter exocytosis and/or nerve sprouting/regrowth to reform the synapse at the neuromuscular junction. (i.e., block nerve muscle communication to establish stable synapse). Alternatively, block synthesis of ion channels. Another target is Choline acetyltransferase.	Prolonged skeletal muscle weakness or flaccidity, reduction of spasticity and/or pain. Duration: > 3 months

The methods used to covalently couple the inactivated *Clostridial* toxins and the chemical agents rely on conventional techniques that are familiar to those having ordinary skill in the art. The provision must be met however, that the domain of the compound that corresponds to the inactivated toxin retains the ability to specifically interact with cognate *Clostridial* toxin r ceptors on target cells.

Purified botulinum toxin type A has be n clinically used as a neurotoxic agent. This compound, which is sold under the trade name BOTOX®, is manufactured by Allergan, Inc. (Irvine, California). This agent is therapeutically used to produce localized chemical denervation muscle paralysis. When chemically denervated in this fashion, the affected muscle atrophies and may develop extrajunctional acetylcholine receptors. It is believed that the affected nerve cells can sprout and reinnervate muscle tissue, thus rendering the paralytic activity of BOTOX® reversible.

Modified *Clostridial* toxins, produced according to the methods described above, will be stored in lyophilized form in containers under vacuum pressure. Prior to lyophilization, the modified toxins will be combined with pharmaceutically acceptable excipients, including albumins and other appropriate agents as would be appreciated by those of ordinary skill in the art. Further information regarding such pharmaceutical preparations can be found in the "Physicians Desk Reference," published annually by Medical Economics Data of Oradell, New Jersey. The lyophilized material will be reconstituted with sterile non-preserved saline prior to intramuscular injection. This dissolved material will then be useful in the treatment of a variety of neuromuscular disorders as described above.

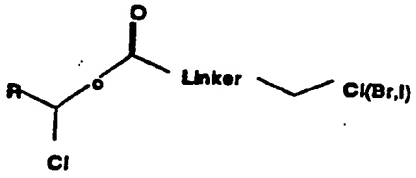
Methods of Linking Chemical Compounds to Light Chain Proteins

Whereas we contemplate that many different chemical compounds will be usefully bonded to toxin transporter molecules, a subset of these compounds will be neuropharmacologic agents or drugs. The following description therefore emphasizes methods of joining transporter proteins and drugs. However, those of ordinary skill in the art will appreciate the more generic term, "chemical compound" can reasonably be substituted for the term, "drug."

Many approaches are known for linking chemical compounds to the amino acid chains f proteins. We will use a linker molecule to separate the drug from the L chain peptide. As discussed above, we discovered that 11 amino acids can be attached to the N-terminus of the TeTx-L chain with out substantially affecting its functionality. For this reason, we will use the N-terminal portion of either the botulinum toxin or tetanus toxin L chain as the compound attachment point.

It is known that most drugs have positions that are not sensitive to steric hindrance. In addition, the linkage process should not introduce chirality into the drug molecule. Further, the linker and the drug should be attached through a covalent bond. The distance between the L chain and drug can be adjusted by the insertion f spacer moieties.

A)



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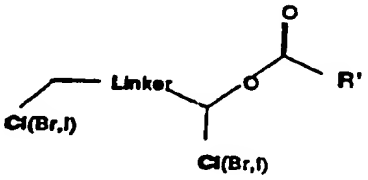
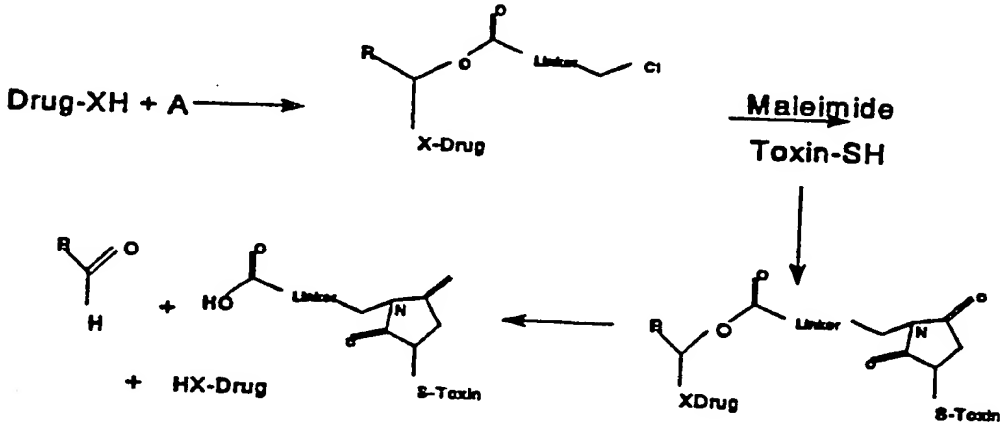
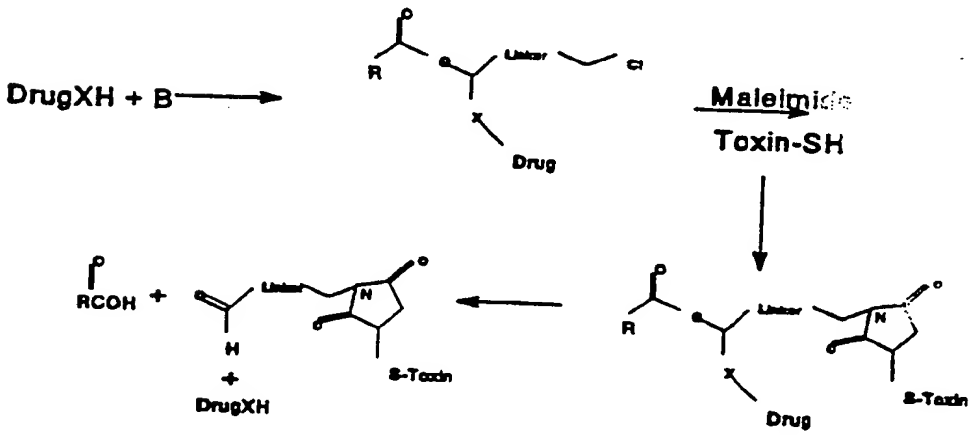


The specific reactions with Linkers A or B are shown below.





Our strategy for linking ribozymes to the t xin transporters employs the free amine functional groups on adenosine and guanosine bases f r linker attachment. In particular, our approach will be to incorporate modified adenosine or guanosine residues that are modified at their free amine positions with a linker that is in turn bound to the nitrogen position of succinimide. The structures of these modified nucleosides can be diagrammed as:

Sugar-Base-NH-Linker-Succinimide

Ribozymes are conventionally prepared by sequentially linking nucleosides in a defined order. The linking reaction occurs between the sugar moieties of the individual chemical units. Incorporation of a modified nucleoside, as described above, at either the 3' or 5' end of the ribozyme will provide a means for covalently linking to the toxin transporter according to the mechanism described previously.

Although other materials and methods similar or equivalent to those described herein can be used in the practice or testing of the present invention, the preferred methods and materials are now described. General references for methods that can be used to perform the various PCR and cloning procedures described herein can be found in *Molecular Cloning: A Laboratory Manual* (Sambrook et al. eds. Cold Spring Harbor Lab Publ. 1989) and *Current Protocols in Molecular Biology* (Ausubel et al. eds., Greene Publishing Associates and Wiley-Interscience 1987).

The initial step in creating an inactivated TeTx composition involved subcloning of the wild-type and mutated L chain structural genes into plasmid expression vectors. The vector employed for this purpose was designed to express a fusion protein that links a maltose-binding protein domain at the N terminus, with L chain sequences at the C terminus. A vector-encoded factor X_a proteolytic cleavage site is interposed between the MBP and L chain insert sequences. Site-directed mutagenesis of the L chain DNA was employed to change Glu^{234} to Ala (Figure 1B).

Example 1 describes the methods used to create recombinant plasmids that encoded maltose-binding fusion proteins of wild-type and mutant tetanus toxin L chain.

Example 1

Preparation of Maltose-Binding-Protein-TeTx-L Chain Constructs

E. coli K-12 strain TG1 was used as a host for the propagation of all plasmid constructs described below. Plasmid pMAL-LC (wild-type L chain gene) was constructed by

purification step was found in the column wash fraction. Fractions of the column wash were monitored for A_{280nm} and checked again by SDS-PAGE and Western blotting.

For amino acid sequencing, recombinant wild-type or mutant L chains were run on SDS-PAGE and transferred onto a poly(vinylidene difluoride) membrane as described by Tous et al., in *Anal. Biochem.* 179:50 (1989), with automated Edman degradation performed on a Model 4000 protein sequencer (Chelsea Instruments, London). Microsequencing of the two products revealed four residues identical to those of the N-terminus of native L chain preceded by the 11 amino acids encoded by the multiple cloning site of the vector as depicted in Figure 1A. Given this success in producing recombinant L chain proteins having the desired structures, we next tested the enzymatic activities of these compositions.

Measurement of the zinc-dependent protease activity of native L chain was employed as an assay for the activity of the recombinant L chain proteins. Two different protein substrates were used in this assay. In the first case, bovine small synaptic vesicles (SSVs) were used. The assay for proteolytic cleavage of the substrate was based on coomassie staining and Western blotting of protein gels.

Example 3 describes the techniques used to assess the proteolytic activities of wild-type and mutant recombinant L chain proteins using SSVs as the substrate.

Example 3

Measurement of TeTx-L Chain-Dependent Proteolysis of *in vitro* Substrates

Native, recombinant wild-type or Ala^{234} L chains were incubated with bovine small synaptic vesicles (SSVs) (0.5 mg/ml) for 90 minutes at 37°C in 50 mM HEPES, 400 mM NaCl, 5 mM DDT, 2 μM $ZnSO_4$ (pH 7.4). Reactions were terminated by the addition of SDS-PAGE sample buffer followed by boiling for 3-5 minutes. Samples were then subject d to SDS-PAGE and detected by Western blotting using affinity-purified anti-HV62 antibody raised against a 62-amino acid synthetic polypeptide corresponding to residues 33-94 of human VAMP 2 as defined by Shone et al., in *Eur. J. Biochem.* 217:965 (1993). The method used to prepare the anti-HV62 antibody was essentially identical to the method described by de Paiva et al. in *J. Neurochem.* 61:2338 (1993). Incubation of the recombinant (100 nM) or authentic (50 nM) L chain proteins with bovine SSVs resulted in proteolytic cleavage of VAMP, as semi-quantitatively assessed by Western blotting with the anti-VAMP antibody probe or protein staining of the digests foll wing SDS-PAGE. The

Ala^{234}-L chain proved inactive as a protease, even at a concentration of 2.3 μM. This result confirmed that Glu^{234} is essential for enzymatic activity of the TeTx-L chain.

To more accurately quantitate the relative activities of the native and recombinant L chains, RP-HPLC was used to measure the cleavage of a synthetic 62-residue polypeptide, HV62, corresponding to residues 33-94 of human VAMP-2.

Example 4 describes the procedure that was used to quantify the *in vitro* activities of native and recombinant L chains using the HV62 peptide substrate.

Example 4

Quantitation of the Proteolytic Activities of
Native and Recombinant TeTx-L Chain Proteins

A stock solution of HV62 peptide (40 μM final concentration, 60 μl final volume) in 20 mM HEPES and 200 mM NaCl (pH 7.4) containing 5 mM DTT was incubated at 37°C with L chain preparations (100 nM final concentration). At timed intervals, the reactions were terminated by the addition of 60 μl of 5 mM ethylenediamine-tetraacetic acid (EDTA) and 1% (v/v) trifluoroacetic acid (TFA) (pH 2) followed by centrifugation. Samples were stored at -20°C until analysis. The extent of HV62 hydrolysis was measured by reverse-phase high-pressure liquid chromatography (RP HPLC) on a Micropax C_{18} column equilibrated in 0.05% TFA using a 0-60% acetonitrile gradient, while monitoring at A_{220nm}. N-Terminal sequencing of the cleavage product confirmed a single proteolytic site between Gln^{76} and Phe^{77}, in accordance with the observations of Schiavo et al., as presented in *EMBO J.* 11:3577 (1992). The percentage of HV62 hydrolysis was calculated from the peak height of the breakdown product that corresponded to residues 77-94. A linear standard curve that related peak height to known quantities of product was used for quantitation.

Quantitation of the separated cleavage product (residues 77-94), time- and concentration-dependent hydrolysis of the polypeptide by native L chain is presented in Figure 2. Cleavage of the HV62 substrate (40 μM) by recombinant L chain (250 nM) confirmed its proteolytic activity. However, a 2.5-fold higher concentration of the recombinant L chain was required to elicit the same level of hydrolysis (n=4) as that bserved for the authentic L chain protein. Under the specified conditions, the initial rates (n=4) of substrate cleavage at 37°C with 100 nM native and recombinant L chain were 45.6±3.6 and 21.6±2.4 pmol/min, respectively. More importantly, proteolysis of the polypeptide (40 μM) was undetectable when Ala^{234}-L chain was incubated for 3 hours at 2.5

μM. This latter finding confirmed that Glu^{234} was essential for catalytic activity of the TeTx-L chain.

The lack of proteolytic activity which characterized the Ala^{234}-L chain mutant could either result from an inability of the L chain to bind the substrate or to cleave the peptide bond (Gln Phe). To distinguish between these possibilities, the Ala^{234} L chain was investigated for the ability to attenuate cleavage of the HV62 substrate by native L chain. This was simply tested by preincubating HV62 with Ala^{234} L chain before the addition of native L chain. To make this test, 9 μM HV62 was preincubated with 4.5 μM Ala^{234}-L chain in reaction buffer at 37°C for 1 hour before the addition of 150 nM native L chain. At the end of the reaction period, the sample was analyzed for substrate cleavage as described above. The results from this procedure indicated that the presence of the Ala^{234}-L chain mutant protein reduced the activity of the native L chain by more than 50% (Figure 2, ins t). This result indicated the mutant L chain retained the ability to bind peptide, thereby inhibiting the proteolytic activity of the native L chain.

Given the demonstration that Ala^{234}-L chain possessed no detectable proteolytic activity, we proceeded to investigate the properties of dichain molecules assembled from native H chain and inactive L chain components. Since the H chain portion of the toxin contributes largely to binding cell surface receptors, we reasoned that a dichain toxin which had lost the ability to proteolyze substrates would conceivably retain the ability to bind at the cell surface and be internalized. Such a dichain species could readily be adapted for use as a vehicle for the delivery of various chemical species to neuronal cells.

Example 5 describes the method used to prepare TeTx dichains that incorporate either native L chain, recombinant wild-type L chain or Ala^{234}-L chain.

Example 5

Reassociation of TeTx from Native H Chain and Recombinant L Chain

Native H chain, purified from TeTx as detailed by Weller et al., in *Eur. J. Biochem.* 182:649 (1989), was combined with an equimolar amount of either native L chain, recombinant wild-type L chain or Ala^{234}-L chain. The mixtures were dialyzed against 2 M urea, 20 mM DTT, 1 M NaCl, and 50 mM Tris-HCl (pH 8.4) with stirring for 18 hours and then further dialyzed without agitation against 50 mM Tris-HCl and 600 mM glycine (pH 8.4) for 72 hours. An aliquot (300 μg) was loaded onto an HPLC DEAE column in 25 mM

Tris-HCl buffer (pH 8.4) and eluted with an NaCl gradient (0-1 M) in th same buffer. The extent of c valent reconstitution was checked by nonreducing SDS-PAGE and silver staining.

The reassociation f dichain species was confirmed by virtue of the presence of stained high M, protein bands that comigrated with native TeTx. With respect to recombinant wild-type and mutant L chains, the relative amounts of the dichain species were 55.1 and 56.8%, respectively, as determined by densitometric scanning of the silver-stained gel. Native H chain and L chain gave similar levels of reconstitution. The latter involved interchain disulfide formation as the toxin was converted back to free H chain and L chain upon reduction by DTT.

With the availability of reassociated dichain toxin molecules, we proceeded to investigate to biological activities of dichains that incorporated recombinant L chains. Although the results of our SDS-PAGE analysis indicated that dichain species had reassociated, this alone was not evidence that the reconstituted proteins were properly folded or that the appropriate inter- and intra-chain disulfide bonds had formed to produce active toxins. Thus, it was necessary to perform a functional assay for toxin activity.

Example 6 describes the methods used to assess the biological activity of the reassociated dichain toxins.

Example 6

Bioassay of Reassociated TeTx Dichain Toxins

Mice (20 g) were injected (200 μl/mouse) subcutaneously into the dorsal neck region with dichain toxin or other samples as described by Fairweather et al., in *Infect. Immunol.* 58:1323 (1990), and LD_{50} values were determined as described by Maisey et al., in *Eur. J. Biochem.* 177:683 (1988). The results of this procedure are presented in Table 2.

The recombinant inactive L chain and native H chain are renatured to produce a dichain molecule of roughly 150 kDa M_r. Renaturation is accomplished by mixing equimolar amounts of L chain and H chain proteins in the presence of urea and DTT. The mixture is dialyzed at 4°C against a buffer that had the same composition as the dialysis buffer employed in Example 5. The buffer is preferably oxygenated during the renaturation process. The buffer is changed 5 times over 24 hours. The removal of urea and DTT leads to the disulfide linkage of the L chain and H chain. Each dichain has several free sulfhydryl groups that are available for drug attachment.

The vesamicol linker is bonded to the free sulfhydryl groups found on the intact transporter molecule by mixing a 5 fold molar excess of the vesamicol linker with the transporter in Tris-NaCl, described above, at 4°C in the dark for 1 to 24 hours. The transporter-vesamicol preparation is then dialyzed against Tris-NaCl overnight to remove excess vesamicol-linker-maleimide from the vesamicol transporter.

The drug-transporter material is then available for administration as a sterile injection in a therapeutically effective dose.

The modified and inactivated TeTx neurotoxin transporter described above will have numerous clinical applications. For example, we anticipate these modified toxins will be useful in the treatment of neuromuscular disorders that affect spasticity in general areas of the body. These disorders include, but are not limited to, spasmodic torticollis, post-stroke or traumatic brain injury induced spasticity.

Example 9 describes how the chemically modified, inactive TeTx transporter described above can be used as a therapeutic agent for delivering chemical compounds to neurons that express toxin receptors.

Example 9

Therapeutic Administration of Modified Toxins:

Spasmodic Torticollis (Cervical Dystonia)

A female, age 45, suffering from spasmodic Torticollis, as manifested by spasmodic r tonic contractions of the neck musculature, producing stereotyped abnormal deviations of the heard, the chin, being rotated to one side, and the shoulder being elevated toward the side at which the head is rotated, is treated by therapeutically effective doses of an appropriate drug, as would be appreciated by one of ordinary skill in the art, attached to an inactive tetanus toxin transporter directly into the affected muscles. After 3-7 days, the

symptoms are substantially alleviated, i.e., the patient is able to hold her head and sh ulder in a normal position or there is a dramatic reduction in the pain and discomf rt.

Example 10 further illustrates how the chemically modified, inactive TeTx transporter described above can be used as a therapeutic agent for delivering chemical compounds to neurons that express toxin receptors.

Example 10

Therapeutic Administration of Modified Toxins:

Post Stroke or Traumatic Brain Injury Induced Spasticity

A young male, age 24, suffering from traumatic brain injury, has developed upper and lower limb spasticity which restricts movement and impedes rehabilitation and hygiene. Symptoms include severe closing of the hand and curling of the wrist and closing of the legs such that the patient and attendant have difficulty with hygiene. In addition, the spastic nature of the limb impedes physical rehabilitation and causes muscle contracture and possibly joint immobilization. Sterile injections of therapeutically effective doses of an appropriate drug, as would be appreciated by one of ordinary skill in the art, attached to an inactive tetanus toxin transporter are administered directly into the affected muscles. Relief of these symptoms occur in 7-21 days such that the lower limbs have relaxed enough to allow the patient and attendant to perform normal hygiene.

A female, age 70, suffering from a cerebral vascular event (stroke) has developed lower limb spasticities which require extensive efforts to maintain hygiene. The patient is injected in both limbs with therapeutically effective doses of an appropriate drug, as would be appreciated by one of ordinary skill in the art, attached to an inactive tetanus toxin transporter. Injections are made directly into the affected muscles. Relief of these symptoms occur in 7-21 days such that the lower limbs have relaxed enough to allow the patient and attendant to perform normal hygiene.

Whereas the foregoing descriptions, results and conclusions have primarily regarded th production, characterization and use of the modified TeTx transporter, parallel discoveries have been made with respect to a modified BoNT/A transporter. Our work with BoNT/A began with the subcloning of the L chain protein coding sequence.

A DNA fragment encoding the BoNT/A-L chain was PCR-amplified using sense and antisense primers that annealed to the 5' and 3' ends of the BoNT/A-L chain gene. The amplification product was ligated into the pBluescript II SK$^+$ vector to create the plasmid, pSAL. As described in the following Example, double-stranded plasmid sequencing verified

that the nucl otide sequence of the clon d L chain gene was identical to that of the authentic BoNT/A-L chain gene.

Example 11 describes the methods used to clone the polynucleotide sequence ncoding the BoNT/A-L chain.

Example 11

Subcloning the BoNT/A-L Chain Gene

The DNA sequence encoding the BoNT/A-L chain was amplified by a PCR protocol that employed synthetic oligonucleotides having the sequences, 5'-AAAGGCCTTTTGTTAATAAACAA-3' (SEQ ID NO: 5) and 5'-GGAATTCTTACTTATTGTATCCTTTA-3' (SEQ ID NO: 6). Use of these primers allowed the introduction of Stu I and EcoR I restriction sites into the 5' and 3' ends of the BoNT/A-L chain gene fragment, respectively. These restriction sites were subsequently used to facilitate unidirectional subcloning of the amplification products. Additionally, these primers introduced a stop codon at the C-terminus of the L chain coding sequence. Chromosomal DNA from *C. botulinum* (strain 63 A) served as a template in the amplification reaction.

The PCR amplification was performed in a 100 μl volume containing 10 mM Tris-HCl (pH 8.3), 50 mM KCl, 1.5 mM $MgCl_2$, 0.2 mM of each deoxynucleotide triphosphate (dNTP), 50 pmol of each primer, 200 ng of genomic DNA and 2.5 units of *Taq*-polymerase (Promega). The reaction mixture was subjected to 35 cycles of denaturation (1 minute at 94° C), annealing (2 minutes at 37°C) and polymerization (2 minutes at 72°C). Finally, the reaction was extended for an additional 5 minutes at 72°C.

The PCR amplification product was digested with Stu I and EcoR I, purified by agarose gel electrophoresis, and ligated into Sma I and EcoR I digested pBluescript II SK$^+$ to yield the plasmid, pSAL. Bacterial transformants harboring this plasmid were isolated by standard procedures. The identity of the cloned L chain polynucleotide was confirmed by double stranded plasmid sequencing using SEQUENASE (United States Biochemicals) according to the manufacturer's instructions. Synthetic oligonucleotide sequencing primers were prepared as necessary to achieve overlapping sequencing runs. The cloned sequence was found to be identical to the sequence disclosed by Binz, et al., in *J. Biol. Chem.* 265:9153 (1990), and Thompson et al., in *Eur. J. Biochem.* 189:73 (1990).

Site-directed mutants designed to compromise the enzymatic activity of the BoNT/A-L chain were also created.

Example 12 describes the method used to construct polynucleotides encoding mutant BoNT/A-L chains.

Example 12

Mutagenesis of the BoNT/A-L Chain Polynucleotide

PCR-mediated mutagenesis of BoNT/A Glu^{224} to Gln or His^{227} to Tyr was performed using the cloned L chain polynucleotide as a template according to a modification of the method described by Higuchi in PCR Protocols, Edited by Innis, Gelfand, Sninsky and White; Academic Press, Inc. (1990). The sense and antisense oligonucleotide primers used to create the Gln^{224} mutant had the sequences, 5'-GCACATCAACTTATACAT-3' (SEQ ID NO:7) and 5'-ATGTATAAGTTGATGTGC-3' (SEQ ID NO:8). The sense and antisense oligonucleotide primers used to create the Tyr^{227} mutant had the sequences, 5'-AACTTATATATGCTGGAC-3' (SEQ ID NO: 9) and 5'-GTCCAGCATATATAAGTT-3'(SEQ ID NO: 10). Secondary PCR, using primers having the sequences of SEQ ID NO:5 and SEQ ID NO:6, amplified the complete mutant genes. The amplified polynucleotide harboring the Gln^{224} mutation was digested with Stu I and EcoR I and ligated to pBluescript II SK^+ vector that had been double-digested with Sma I and EcoR I, to create the plasmid, pSAL-Gln^{224}. The amplified polynucleotide harboring the Tyr^{227} mutation was digested with Stu I and EcoR I, and ligated to pBluescript II SK^+ vector that had been double-digested with Sma I and EcoR I, to create the plasmid, pSAL-Tyr^{227}.

Polynucleotides encoding recombinant L chains were cleaved from their respective plasmids and ligated into prokaryotic expression vectors to facilitate the production of fusion proteins in bacteria. The pMAL-c2 vector was employed to create expression plasmids capable of directing the high level expression of maltose binding fusion proteins. As disclosed in Example 21 (see later), the pGEX-2T vector (Pharmacia) was similarly employed for the production of glutathione S-transferase (GST) fusion proteins with equally good results. Although we have produced and tested the GST fusion proteins, we have found that fusion proteins incorporating maltose binding domains can advantageously be purified with particular ease. The L chain protein coding sequences in all of the expression constructs described herein were under the transcriptional control of vector-borne, IPTG-inducible P_{tac} promoters.

Example 13 describes the methods used to construct plasmids that directed expression of the BoNT/A wild-type and mutant L chains as maltose binding fusion proteins in bacterial host cells.

Example 13

Construction f a Recombinant BoNT/A-L Chain Expression Plasmids

The BoNT/A wild-type and mutant L chain polynucleotides, carried by the pSAL, pSAL-Gln^{224} and pSAL-Tyr^{227} plasmids, were excised by digestion with BamH I and Sal I and then ligated between the BamH I and Sal I sites of the pMAL-c2 expression vector (New England BioLabs) to produce the plasmids pCAL, pCAL-Gln^{224} and pCAL-Tyr^{227}. The pCAL plasmid is diagrammed in Figure 5. The pCAL pCAL-Gln^{224} and pCAL-Tyr^{227} plasmids are identical except for the mutation of single codons as specified above. The pMAL-c2 vector harbors the *MalE* gene, which encodes the maltose binding protein (MBP), under transcriptional control of the IPTG-inducible P_{tac} promoter. A multiple cloning site (MCS) within this plasmid permitted subcloning of the L chain coding sequences at the 3' end of the *MalE* coding sequences. Importantly, a Factor X_a protease cleavage sequence was present between the *MalE* and the L chain sequences of the fusion proteins. Transformed *E. coli* TG1 harboring the expression plasmids were isolated by standard methods.

The structures of the pCAL, pCAL-Gln^{224} and pCAL-Tyr^{227} plasmids were verified by restriction enzyme digestion and agarose gel electrophoresis. DNA sequence analysis confirmed that the inserts present in these plasmids were correctly orientated with respect to the translational reading frame of the authentic L chain gene. Sequence analysis also confirmed that the 5' ends of the L chain genes were fused to the MCS and Factor X_a cleavage sites via short sequences that encoded seven amino acids, as expected. Moreover, the DNA sequencing results indicated that the L chain sequences and the linked *MalE* sequences were in the same translational reading frames.

With the availability of bacterial clones that harbored expression plasmids encoding the recombinant L chains, it became possible to produce useful quantities of both wild-type and mutant BoNT/A-L chain proteins. Similar procedures were employed for the production and purification of wild-type and mutant L chain fusion proteins. While the following Example presents the procedures employed using the wild-type and Try^{227} mutant fusion proteins, identical methods were applicable to production of fusion proteins harboring the Gln^{224} mutation.

Example 14 describes the methods used to verify expression of the wild-type and mutant L chains in bacteria harboring the pCAL and pCAL-Tyr^{227} plasmids.

Example 14

Expression of the BoNT/A-L Chain Fusion Proteins

Well isolated bacterial colonies harboring either pCAL or pCAL-Tyr^{227} were used to inoculate L-broth containing 100 μg/ml ampicillin and 2% (w/v) glucose, and grown overnight with shaking at 30°C. The overnight cultures were diluted 1:10 into fresh L-broth containing 100 μg/ml of ampicillin and incubated for 2 hours. Fusion protein expression was induced by addition of IPTG to a final concentration of 0.1 mM. After an additional 4 hour incubation at 30°C, bacteria were collected by centrifugation at 6,000 x g for 10 minutes.

A small-scale SDS-PAGE analysis confirmed the presence of a 90 kDa protein band in samples derived from IPTG-induced bacteria. This M_r was consistent with the predicted size of a fusion protein having MBP (~40 kDa) and BoNT/A-L chain (~50 kDa) components. Furthermore, when compared with samples isolated from control cultures, the IPTG-induced clones contained substantially larger amounts of the fusion protein.

The presence of the desired fusion proteins in IPTG-induced bacterial extracts was also confirmed by Western blotting using the polyclonal anti-L chain probe described by Cenci di Bello et al., in *Eur. J. Biochem.* 219:161 (1993). Reactive bands on PVDF membranes (Pharmacia; Milton Keynes, UK) were visualized using an anti-rabbit immunoglobulin conjugated to horseradish peroxidase (Bio-Rad; Hemel Hempstead, UK) and the ECL detection system (Amersham, UK). Western blotting results confirmed the presence of the dominant fusion protein together with several faint bands corresponding to proteins of lower M_r than the fully sized fusion protein. This observation suggested that limited degradation of the fusion protein occurred in the bacteria or during the isolation procedure. Neither the use of 1 mM nor 10 mM benzamidine (Sigma; Poole, UK) during the isolation procedure eliminated this proteolytic breakdown.

The yield of intact fusion protein isolated by the above procedure remained fully adequate for all procedures described herein. Based on estimates from stained SDS-PAGE gels, the bacterial clones induced with IPTG yielded 5 - 10 mg of total MBP-wild-type or mutant L chain fusion protein per liter of culture. Thus, the method of producing BoNT/A-L chain fusion proteins disclosed herein was highly efficient, despite any limited proteolysis that did occur.

The MBP-L chain fusion proteins encoded by the pCAL and pCAL-Tyr^{227} expression plasmids were purified from bacteria by amylose affinity chromatography. Recombinant wild-type or mutant L chains were then separated from the sugar binding d mains of the

fusion proteins by site-specific cleavage with Factor X_a. This cleavage procedure yielded free MBP, free L chains and a small amount of uncleaved fusion protein. While the resulting L chains present in such mixtures have been shown to possess the desired activities, we have also employed an additional purification step. Accordingly, the mixture of cleavage products was applied to a second amylose affinity column that bound both the MBP and uncleaved fusion protein. Free L chains were not retained on the affinity column, and were isolated for use in experiments described below.

Example 15 describes the method used to produce and purify both wild-type and Tyr^{227} mutant recombinant BoNT/A light chains from bacterial clones.

Example 15

Purification of Fusion Proteins and Isolation of Recombinant BoNT/A-L Chains

Pellets from 1 liter cultures of bacteria expressing either the wild-type or the mutated BoNT/A-L chain proteins were resuspended in column buffer [10 mM Tris-HCl (pH 8.0), 200 mM NaCl, 1 mM EGTA and 1 mM DTT] containing 1 mM phenyl-methanesulfonyl fluoride (PMSF) and 10 mM benzamidine, and lysed by sonication. The lysates were cleared by centrifugation at 15,000 x g for 15 minutes at 4°C. Supernatants were applied to an amylose affinity column [2 x 10 cm, 30 ml resin] (New England BioLabs; Hitchin, UK). Unbound proteins were washed from the resin with column buffer until the eluate was free of protein as judged by a stable absorbance reading at 280 nm. The bound MBP-L chain fusion protein was subsequently eluted with column buffer containing 10 mM maltose. Fractions containing the fusion protein were pooled and dialyzed against 20 mM Tris-HCl (pH 8.0) supplemented with 150 mM NaCl, 2 mM, $CaCl_2$ and 1 mM DTT for 72 hours at 4°C.

Fusion proteins were cleaved with Factor X_a (Promega; Southampton, UK) at an enzyme:substrate ratio of 1:100 while dialyzing against a buffer of 20 mM Tris-HCl (pH 8.0) supplemented with 150 mM NaCl, 2 mM, $CaCl_2$ and 1 mM DTT. Dialysis was carried out for 24 hours at 4°C. The mixture of MBP and either wild-type or mutant L chain that resulted from the cleavage step was loaded onto a 10 ml amylose column equilibrated with column buffer. Aliquots of the flow through fractions were prepared for SDS-PAGE analysis to identify samples containing the L chains. Remaining portions of the flow through fractions were stored at -20°C. Total *E. coli* xtract or the purified proteins wer solubilized in SDS sample buffer and subjected to PAGE according to standard procedures. R sults of this

procedure indicated the recombinant toxin fragment accounted for roughly 90% of the protein content of the sample.

The foregoing results indicated that the approach to creating MBP-L chain fusion proteins described herein could be used to efficiently produce wild-type and mutant recombinant BoNT/A-L chains. Further, our results demonstrated that recombinant L chains could be separated from the maltose binding domains of the fusion proteins and purified thereafter. While these results directly addressed certain structural properties of the recombinant L chains, the functional properties of these proteins remained to be determined. Thus, we proceeded to investigate the enzymatic activities of the wild-type and mutant recombinant L chains.

A sensitive antibody-based assay was developed to compare the enzymatic activities of recombinant L chain products and their native counterparts. The assay employed an antibody having specificity for the intact C-terminal region of SNAP-25 that corresponded to the BoNT/A cleavage site. Western Blotting of the reaction products of BoNT/A cleavage of SNAP-25 indicated an inability of the antibody to bind SNAP-25 sub-fragments. Thus, the antibody reagent employed in the following Example detected only intact SNAP-25. The loss of antibody binding served as an indicator of SNAP-25 proteolysis mediated by added BoNT/A light chain or recombinant derivatives thereof.

Example 16 describes the method used to demonstrate that both native and recombinant BoNT/A-L chains, but not Tyr^{227} mutant L chains, can proteolyze a SNAP-25 substrate. Notably, although the Tyr^{227} mutant L chain was employed in this Example, the Gln^{224} mutant L chain gave identical results in the SNAP-25 cleavage assay.

Example 16

Evaluation of the Proteolytic Activities of Recombinant L Chains Against a SNAP-25 Substrate

A quantitative assay was employed to compare the abilities of the wild-type and mutant BoNT/A-L chains, and their recombinant analogs, to cleave a SNAP-25 substrate. The substrate utilized for this assay was obtained by preparing a glutathione-S-transferase (GST)-SNAP-25 fusion protein, containing a cleavage site for thrombin, expressed using the pGEX-2T vector and purified by affinity chromatography on glutathione agarose. The SNAP-25 was then cleaved from the fusion protein using thrombin in 50 mM Tris-HCl (pH 7.5) containing 150 mM NaCl and 2.5 mM $CaCl_2$ (Smith et al., *Gene* 67:31 (1988)) at an enzyme:substrate ratio of 1:100. Uncleaved fusion protein and the cleaved glutathione-

Given that a single point mutation could eliminate the proteolytic activity of recombinant L chains, we proceeded to reconstitute dichain molecules that incorporated mutant L chains as a means for creating inactive BoNT/A neurotoxins. Purified recombinant wild-type and Tyr^{227} mutant L chains, in the absence of the sugar binding domains of the parent fusion proteins, were reconstituted with native H chain isolated from BoNT/A. Formation of the ~150 kDa disulfide-linked dichain toxin was confirmed by SDS-PAGE under non-reducing conditions. Quantitative analysis revealed that the recombinant L chains reassociated with the native H chain protein to form dichains less efficiently than did the native L chain protein. This difference may reflect a divergence between the folded structures of the recombinant and native proteins.

Example 18 describes the method used to reassociate dichain toxins having H and L chains. Dichains incorporating either native, recombinant wild-type or mutant BoNT/A-L chains were reassociated by this procedure. While the Tyr^{227} mutant L chain is employed in the Example, those having ordinary skill in the art will appreciate that other mutant L chains can be associated with native H chains by the same procedure.

Example 18

Reconstitution of Native L Chain, Recombinant Wild-Type or Tyr^{227} Mutant L Chain with Purified H Chain

Native H and L chains were dissociated from BoNT/A (List Biologicals Inc.; Campbell, USA) with 2 M urea, reduced with 100 mM DTT and then purified according to established chromatographic procedures (Kozaki et al., *Japan J. Med. Sci. Biol.* 34:61 (1981); Maisey et al., *Eur. J. Biochem.* 177:683 (1988)). Purified H chain was combined with an equimolar amount of either native L chain, recombinant wild-type L chain or the Tyr^{227} mutant L chain. Reconstitution was carried out by dialyzing the samples against a buffer consisting of 25 mM Tris (pH 8.0), 50 μM zinc acetate and 150 mM NaCl over 4 days at 4°C. Following dialysis, the association of the recombinant L chain and native H chain to form disulfide-linked 150 kDa dichains was monitored by SDS-PAGE and quantified by densitometric scanning. The proportion of dichain molecules formed with the recombinant L chains was lower than that obtained when native L chain was employed. Indeed, only about 30% of the recombinant wild-type or mutant L chain was reconstituted while >90% of the native L chain reassociated with the H chain. In spite of this lower efficiency of reconstitution, sufficient material incorporating the recombinant L chains was easily produced for use in subsequent functional studies.

Dichain molecules harboring mutant L chains had novel properti s when compared with reconstituted dichains having either native r wild-type recombinant L chains in *in vitro* physiological assays. Following dialysis, the reconstituted material described in the previous Example was applied to the medium bathing excised mouse phrenic nerve-hemidiaphragms. As disclosed below, dichains reconstituted using either native or wild-type recombinant L chains effectively blocked neuromuscular transmission in this assay. In contrast, dichain molecules reconstituted using the mutant L chain were completely inactive.

Example 19 describes the method used to demonstrate modified functional properties of reconstituted dichain toxins that incorporate recombinant L chains.

Example 19

Assessment of the Effect of Reconstituted Toxins on Neuromuscular Transmission

Mouse phrenic nerve-hemidiaphragms were excised from Balb/C mice (20 - 25 g) and bathed in a closed circulatory superfusion system containing 10 ml of aerated Krebs-Ringer composed of (mM): NaCl, 118.0; KCl, 4.7; $MgSO_4$, 1.2; $CaCl_2$, 2.5; $NaHCO_3$, 23.8; KH_2PO_4, 1.2; glucose, 11.7, pH 7.4 (de Paiva et al, *J. Biol. Chem.* 268:20838 (1993)). Muscle twitch was evoked by supramaximal stimulation of the phrenic nerve and measured using a force-displacement transducer (Simpson *J. Pharmacol. Exp. Ther.* 212:16 (1980)).

The results presented in Figure 8 indicated that a dichain toxin reconstituted using the wild-type recombinant L chain blocked neuromuscular transmission nearly as effectively as a dichain that had been reconstituted using native L chains. The blockade of transmission by these reconstituted proteins was reversed upon the application of 0.3 mM 4-aminopyridine, a blocker of voltage-gated K^+ channels which temporarily restores nerve-voked muscle tension at BoNT/A-poisoned synapses (Simpson *J. Pharmacol. Exp. Ther.* 245:867 (1988)). This finding proved that the inhibition by the recombinant L chain-containing sample resulted from a presynaptic blockade of transmitter release. Thus, the dichain toxin containing the wild-type recombinant L chain mimicked the activity of BoNT/A in this assay.

In contrast, the dichain material incorporating the Tyr^{227} mutant L chain had no effect on nerve-evoked muscle twitch, even when tested at high concentrations. This absence of activity that characterized a dichain molecule that included a mutant L chain was fully nsistent with the results of the SNAP-25 cleavage assay presented above. Significantly,

results obtained in the nerve-hemidiaphragm assay extend the loss of activity to a clinically-relevant model at the toxin's site of action.

To further demonstrate the properties of dichain molecules that incorporate recombinant L chains, an experiment was carried out to test the abilities of these agents to cause botulism symptoms in mice.

Example 20 describes the methods used to prove that reconstituted dichains incorporating native or wild-type recombinant L chains, but not mutant L chains, had neurotoxic activity *in vivo*.

Example 20

Assessment of the Mouse Lethality of Reconstituted Toxins and their Effect on Neuromuscular Transmission

The ability of the reconstituted dichains to induce botulism was evaluated following intraperitoneal injection of laboratory mice. Results were expressed as the number of doses, lethal within 4 days, present per mg of protein (LD_{50}/mg) (Maisey et al., *Eur. J. Biochem.* 177:683 (1988)).

Toxicity of the dichain material containing the wild-type recombinant L chain (6×10^7 LD_{50}/mg) was comparable to that of the dichain that had been reconstituted using native L chains (7×10^7 LD_{50}/mg). Mice injected with the dichain that had been reconstituted using the Tyr^{227} mutant showed no signs of botulism within four days. Therefore, by all *in vitro* and *in vivo* assays disclosed herein, the recombinant wild-type L chain expressed in *E. coli* is comparable to the potency of its native counterpart, while the mutated Tyr^{227} L chain is devoid of activity.

To illustrate the general utility of recombinant BoNT/A-L chains prepared according to the method disclosed herein, we produced a second set of mutant fusion proteins that were devoid of proteolytic activity. More specifically, we demonstrated that mutagenesis f Glu^{224} to Gln could eliminate enzymatic activity associated with the wild-type BoNT/A-L chain. Further, by employing a GST fusion protein in this demonstration, we confirmed the generality of our approach to producing recombinant BoNT/A-L chains.

Example 21 describes the methods used to construct a polynucleotide encoding a Gln^{224} mutant BoNT/A-L chain fusion with the GST protein.

Example 21

Preparation and Expression of BoNT/A-L Chain Fusions with GST

Polynucleotides encoding the BoNT/A wild-type, Gln^{224} mutant and Tyr^{227} mutant L chains were pr pared exactly as described in Example 11 and Example 12. The amplification products were digested with Stu I and EcoR I, purified by agarose gel electrophoresis and ligated between the Sma I and EcoR I sites of the pGEX-2T expression vector (Pharmacia) to produce the plasmids pTAL-wild-type(GST), pTAL-Gln^{224}(GST) and pTAL-Tyr^{227}(GST). *E. coli* XL1-Blue transformants harboring the plasmids were isolated by standard methods.

Cultures of *E. coli* containing the expression constructs were induced to express the ncoded fusion proteins exactly as described under Example 14. Following lysis of the cells, the GST fusion proteins were purified by glutathione affinity chromatography according to methods familiar to one having ordinary skill in the art. The GST fusion proteins were subsequently tested for proteolytic activity in an *in vitro* assay.

Example 22 describes the methods used to assess the proteolytic activity of the mutant BoNT/A-L chain GST fusion proteins.

Example 22

Characterization of the BoNT/A-L Chain GST Fusions

The proteolytic activity of the isolated GST mutant L chain fusion protein toward a SNAP-25 substrate was assessed. After incubation of the purified mutant L chain fusion proteins and a recombinant GST-SNAP-25 substrate in 50 mM Tris-HCl (pH 8.0) for 2 hours or at 22°C overnight, the products were analyzed by SDS-PAGE. Results of the analysis indicated that the mutant displayed no detectable proteolytic activity toward the SNAP-25 analog. In contrast, the wild-type recombinant L chain fusion protein proteolyzed the ubstrate. Thus, the GST mutant BoNT/A-L chain fusion protein, like the MBP mutant fusion protein, was enzymatically inactive. Further, the GST fusion protein having wild-type BoNT/A-L chain sequences was enzymatically active against the SNAP-25 substrate.

These results confirmed the importance of the amino acids making up the conserved HExxH motif of the BoNT/A-L chain, and demonstrated that fusion proteins other than MBP fusion proteins, can be used to produce recombinant proteins useful in the practice of the present invention. Whether formed as a GST fusion protein or as an MBP fusion protein, recombinant mutant BoNT/A L chains were devoid of the activities that characterized the native toxin, or reconstituted dichains that incorporated recombinant wild-type L chains.

The preceding Examples have illustrated how *Clostridial* L chains can be engineered f r expression in recombinant form as active or attenuated molecules. These L chains have been reconstituted with native H chains to produce dichain molecul s that possessed or

lacked biological activities at the l vel of neuromuscular transmission. The following Example provides compelling evidence that dichain transporter molecules can be used as vehicles for the intracellular delivery of linked molecules.

A hybrid "tri-chain" molecule was used to make this exemplary demonstration. More specifically, a BoNT/A-L chain that was inactivated by virtue of a Gln^{224}/Tyr^{227} double mutation was fused to an active portion of the TeTx-L chain. The resulting recombinant protein was reconstituted with the native BoNT/A-H chain to produce a "tri-chain." This tri-chain complex could bind and enter target neurons. Since the double mutant BoNT/A-L chain was devoid of enzymatic activity, neurotoxicity associated with the tri-chain was necessarily attributable to the presence of an active TeTx component. The results presented in the following Example confirmed that the transporter could be internalized by target cells and could deliver a linked molecule to the cytosol and the transported protein was active intracellularly. As disclosed below, a biochemical test ruled out any neurotoxic activity related to the BoNT/A-L chain.

Example 23 describes the method used to prove that transporters comprising inactive *Clostridial* L chains can be internalized into peripheral cholinergic nerve endings. Further, the results presented below indicated that such transporters were capable of delivering a linked molecule to the cytosol of target neurons in a state that retained biological activity intracellularly.

Example 23

Clostridial Toxin Transporters as Vehicles for Biochemical Delivery

The L chain component of the tri-chain was produced according to the scheme presented in Figure 9. A double mutation (Glu^{224} to Gln^{224} and His^{227} to Tyr^{227}) was introduced into the BoNT/A-L chain by PCR mutagenesis. The primers and the methods utilized to generate the double mutant were the same as those used to produce the Tyr^{227} mutant, except that the Gln^{224} mutant was used as a template. The double mutant (dm) L chain was first cloned into pBluescript SK+II, to form pSALdm, and thereafter cloned into pMAL-c2 to yield pCALdm. The pCALdm construct was employed to express the fusion protein having a maltose binding domain and a BoNT/A-L chain domain bearing a double mutation (MBP-BoNT/A dm). The pCALdm construct is labeled as "1" in Figure 9. The TeTx-L chain was truncated by a PCR protoc l using a polynucleotide harboring the cloned wild-type gene sequence as a template, together with primers having the sequences, 5'-

ATTTCACCAATAACCATAAATAATTTTAG-3' (SEQ ID NO:12) and 5'-CGGGATCCTTCTGTATCATTGTAAAT-3' (SEQ ID NO:13). The amplification product ncod d two additional amino acids at the N-terminus and was truncated at Gly^{399}. The last 58 residues, including Cys^{439} which is normally responsible for disulfide bonding to H chain in native TeTx, was deleted. After cleavage with BamHI, the resulting DNA fragment was cloned into XmnI- and BamHI- digested pMAL-c2 to produce pCTL399. The MBP-truncated TeTx-L chain-BoNT/A-L chain dm gene fusion, pCTLALdm, was prepared by ligating the excised BoNT/A-L chain dm gene to BamHI- and SalI- digested pCTL399. The pCTLALdm construct, labeled as "2" in Figure 9, was used to express the MBP-TeTx truncated L chain-BoNT/A-L chain dm fusion protein in *E. coli*.

Purified MBP-BoNT/A dm of L chain fusion protein encoded by the pCALdm construct failed to cleave a recombinant SNAP-25 substrate in an assay conducted according to the method of Example 16. Thus, the BoNT/A-L chain double mutant fusion protein was devoid of enzymatic activity, as expected. Following cleavage of the fusion protein with Factor X_a, purified BoNT/A-L chain double mutants were reconstituted with native BoNT/A-H chains to form dichain molecules. These dichains failed to block neuromuscular transmission at the mouse hemidiaphragm when tested by the method of Example 19. Thus, the dichain that incorporated the double mutant BoNT/A-L chain was devoid of biological activity in this *in vitro* assay, also as expected. Finally, the reconstituted dichain that incorporated the double mutant BoNT/A-L chain was non-toxic when injected into mice according to the method of Example 20. This was true even when the dichain that incorporated the double mutant BoNT/A-L chain was injected in an amount that was 200 fold greater than the LD_{50} dose of native BoNT/A.

These results indicated that the Gln^{224}/Tyr^{227} double mutation eliminated all toxic properties associated with the native BoNT/A molecule. Accordingly, any toxic activity associated with a transporter that incorporated the L chain double mutant must be attributed to a molecule linked to the inactive BoNT/A-L chain, since the transporter itself was devoid of toxic activity. Accordingly, the reconstituted dichain that incorporated the double mutant B NT/A-L chain represented an ideal cholinergic transporter.

The purified TeTx truncated L chain-BoNT/A-L chain dm fusion protein, encoded by pCTLALdm, exhibited activities that were characteristic of TeTx, but not of BoNT/A. More specifically, the pCTLALdm-encoded fusion protein exhibited an ability to cleave synaptobrevin from neuronal membranes in a concentration dependent manner. This activity

was not contributed by the BoNT/A L chain component of the complex, and highlighted the retention of endoprotease activity by the truncated TeTx-L chain component of the fusion. As expected, the pCTLALdm-encoded fusion protein lacked the ability to cleave a recombinant SNAP-25 substrate. This confirmed the successful elimination of enzymatic activity associated with the BoNT/A-L chain component of the fusion. After cleavage of the pCTLALdm-encoded fusion protein with Factor X_a, the released toxin hybrid was reconstituted with native BoNT/A-H chain to yield the tri-chain.

Most importantly, the tri-chain preparation produced symptoms characteristic of botulism both *in vitro* and *in vivo*. The tri-chain, at a 2 nM concentration, blocked nerve-evoked muscle twitch of mouse hemidiaphragm in 161 min at 24°C, and gave a mouse toxicity of $>10^7$ LD_{50}/mg. It should be noted that it was not, however, possible to provide exact quantitative data on the efficacy of this protein due to the presence of free MBP, uncleaved fusion protein and some native H chain in the reconstituted samples which preclude precise measurement of the amount of "tri-chain" present. Importantly, the block observed with the tri-chain in the hemidiaphragm assay was not reversed by 4-aminopyridine, a voltage-gated K^+ channel blocker which reverses BoNT/A but not TeTx-induced inhibition of neuromuscular transmission. Moreover, a contribution of the H chain (or any contaminating native BoNT/A) to the observed toxicity was ruled out by the observed absence of neuromuscular paralytic activity from larger quantities of the H chain that was used in the reconstitution and treated in an identical manner to the tri-chain material.

These results proved that the transporter targets motor nerve endings, becomes internalized, and can act as a vehicle to transport the linked segment of the TeTx-L chain to the cytosol. Additionally, the linked segment of the TeTx-L chain retained its biological activity following delivery into cholinergic nerves. The utility of this novel transporter as a drug delivery system for acetylcholine containing neurons has been clearly established.

In addition to the L chain modification strategy described in the preceding Example, native or recombinant botulinum toxin L chain proteins can be covalently linked to a chemical compound according to the method detailed in Example 8. The resulting transporter will then be available for administration as a sterile injection in a therapeutically effective dose.

The modified BoNT/A toxin transporters described above will have numerous clinical applications. For example, the BoNT/A-based transporters can be use to deliver therapeutically useful drugs to the peripheral motor terminal. Accordingly, these drugs delivered in this fashion will be useful in controlling limited numbers f muscle groups.

Among the maladies that will be investigated as therapeutic targets are: tardive dyskinesia, spastic colitis, essential tremor, smooth muscle abnormalities, localized spasticity, painful muscle spasms localized to back or other muscle groups, temporal mandibular disorders, spasmodic dysphonia and tension headaches.

Example 24 describes how the chemically modified inactive BoNT/A toxin transporter described above can be used as a therapeutic agents for delivering chemical compounds to neurons that express toxin receptors.

Example 24

Therapeutic Administration of Modified Toxins:

Tardive Dyskinesia

A male patient, age 45, suffering from tardive dyskinesia resulting from the treatment with an antipsychotic drug, such as Thorazine or Haldo, is treated with therapeutically effective doses of an appropriate drug, as would be appreciated by one of ordinary skill in the art, attached to an inactive botulinum toxin transporter directly into the facial muscle muscles. After 1-3 days, the symptoms of tardive dyskinesia, i.e., orofacial dyskinesia, athetosis, dystonia, chorea, tics and facial grimacing, etc. are markedly reduced.

Example 25 further illustrates how the chemically modified inactive toxins described above can be used as therapeutic agents for delivering chemical compounds to neurons that express toxin receptors.

Example 25

Therapeutic Administration of Modified Toxins:

Essential Tremor

A male, age 45, suffering from essential tremor, which is manifested as a rhythmical oscillation of head or hand muscles and is provoked by maintenance of posture or movement, is treated by injection with therapeutically effective doses of a drug (see list in previous table in patent application) attached to an inactive botulinum toxin transporter directly into the affected muscles. The muscles may be identified with the aide of electromyography (EMG). After one to two weeks, the symptoms are substantially alleviated; i.e., the patent's head or hand cases to oscillate.

Example 26 further illustrates how the chemically modified inactive BoNT/A toxin transporter described above can be used as therapeutic agents for delivering chemical compounds to neurons that express toxin receptors.

Exampl 26

Therapeutic Administration of Modified Toxins:

Smooth Muscle Abnormality

A female, age 30, with a constricted lower esophagus (disease called Achalasia) manifests symptoms which prevent food ingestion. Due to the lower esophagus contraction, food and fluid accumulate and eventually is regurgitated, preventing the patient from obtaining adequate nutrition. Therapeutically effective doses of a drug (see list in previous table in patent application) attached to an inactive botulinum toxin transporter is administered directly into the affected sphincter muscles. Usually the injections are administered in 2 to 4 quadrants with any endoscopic device or during surgery. In about 1-7 days, normal passage of solids and liquids into the stomach is achieved resulting in an elimination or reduction in regurgitation.

Example 27 further illustrates how the chemically modified inactive BoNT/A toxin transporter described above can be used as a therapeutic agent for delivering chemical compounds to neurons that express toxin receptors.

Example 27

Therapeutic Administration of Modified Toxins:

Spasmodic Dystonia (Overactive Vocal Chords)

A male, age 45, unable to speak clearly, due to spasm of the vocal chords, is treated by injection of the vocal chords by injection of therapeutically effective doses of an appropriate drug, as would be appreciated by one of ordinary skill in the art, attached to an inactive botulinum toxin transporter. After 1 to 7 days, the patient is able to speak clearly.

Thus, Example 27 shows another use for the inactive clostridial toxins of the present invention. In yet another use, the inactive toxins can be used in the treatment of botulism or tetanus. For such treatment, the inactive clostridial toxin is conjugated to an active ingredient for treatment of botulism or tetanus, such as Captopril or another zinc protease inhibitor. A patient stricken with botulism or tetanus can be treated by administration of a therapeutically effective dose of the conjugate, such as through intramuscular injection. The proper therapeutically effective dose for any particular transporter/drug conjugate can be mpirically determined using techniques readily known to those having ordinary skill in the art.

The inactive toxin alone can also be us d as an immediat antid te to individuals exposed to botulinum toxin. For this purpose, administration should preferably be by

injecti n of at l ast 1 mg of inactive toxin. Higher doses may be necessary in individuals exposed to high r levels of toxin. For this purpose, the inactive toxin alone can be used, without conjugation to another drug. It is believed that the use of this transporter will be more effective in treatment of botulinum toxin poisoning than prior art techniques, such as administration of botulinum toxin antisera.

In summary, we have gained further insight into the action of the TeTx and BoNT/A toxins by employing recombinant DNA techniques to produce L chain protein in useful quantities. Utilizing a PCR-based protocol, the genes encoding the L chains were amplified, subsequently cloned into expression vectors and expressed at high levels in *E. coli*. After purification from the cytosolic fraction using amylose affinity chromatography, fusion proteins representing wild-type sequences were found to proteolytically cleave a recombinant form of the substrate for BoNT/A, synaptosomal-associated protein of M, 25 kDa (SNAP-25). Moreover, once enzymatically cleaved from the maltose binding protein, the recombinant L chain proteins were shown to exhibit properties like those of the native proteins. Also, the expressed L chains were reconstituted with purified native H chains to form disulfide linked dichain proteins which inhibited nerve-evoked neuromuscular transmission *in vitro* and produced the symptoms of botulism in mice.

Most significantly, we also discovered that single amino acid substitutions in the s quence of the L chain proteins completely abrogated the proteolytic activity ordinarily associated with the wild-type proteins. This now allows the formation of dichain toxins that are attenuated by virtue of incorporating a proteolytically inactive L chain.

We also anticipate that single genes that incorporate appropriate site directed mutations can be produced for each of the neurotoxins so that attenuated toxins can be produced in bacteria. This approach will advantageously avoid the need to reconstitute dichain molecules from components. The resulting attenuated toxin can advantageously serve as a transporter for delivering covalently linked chemical compounds to neuronal cells that express toxin receptors.

20

TTATACATGT ACTACATGGT

(2) INFORMATION FOR SEQ ID NO:5:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 23 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA
(iii) HYPOTHETICAL: NO
(iv) ANTISENSE: NO
(v) FRAGMENT TYPE:
(vi) ORIGINAL SOURCE:

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

23

AAAGGCCTTT TGTTAATAAA CAA

(2) INFORMATION FOR SEQ ID NO:6:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 26 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA
(iii) HYPOTHETICAL: NO
(iv) ANTISENSE: YES
(v) FRAGMENT TYPE:
(vi) ORIGINAL SOURCE:

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

26

GGAATTCTTA CTTATTGTAT CCTTTA

(2) INFORMATION FOR SEQ ID NO:7:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 18 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA
(iii) HYPOTHETICAL: NO
(iv) ANTISENSE: NO
(v) FRAGMENT TYPE:
(vi) ORIGINAL SOURCE:

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

18

GCACATCAAC TTATACAT

(2) INFORMATION FOR SEQ ID NO:8:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 18 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA
(iii) HYPOTHETICAL: NO
(iv) ANTISENSE: YES
(v) FRAGMENT TYPE:
(vi) ORIGINAL SOURCE:

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

ATGTATAAGT TGATGTGC 18

(2) INFORMATION FOR SEQ ID NO:9:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 18 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA
(iii) HYPOTHETICAL: NO
(iv) ANTISENSE: NO
(v) FRAGMENT TYPE:
(vi) ORIGINAL SOURCE:

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

AACTTATATA TGCTGGAC 18

(2) INFORMATION FOR SEQ ID NO:10:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 18 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA
(iii) HYPOTHETICAL: NO
(iv) ANTISENSE: YES
(v) FRAGMENT TYPE:
(vi) ORIGINAL SOURCE:

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

GTCCAGCATA TATAAGTT 18

(2) INFORMATION FOR SEQ ID NO:11:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 13 amino acids
(B) TYPE: amino acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide
(iii) HYPOTHETICAL: NO
(iv) ANTISENSE: NO
(v) FRAGMENT TYPE: C-terminal
(vi) ORIGINAL SOURCE:

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

Cys Ala Asn Gln Arg Ala Thr Lys Met Leu Gly Ser Gly
1 5 10

(2) INFORMATION FOR SEQ ID NO:12:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 29 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA
(iii) HYPOTHETICAL: NO
(iv) ANTISENSE: NO
(v) FRAGMENT TYPE:
(vi) ORIGINAL SOURCE:

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:12:

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(2) INFORMATION FOR SEQ ID NO:13:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 26 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA
(iii) HYPOTHETICAL: NO
(iv) ANTISENSE: YES
(v) FRAGMENT TYPE:
(vi) ORIGINAL SOURCE:

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:13:

CGGGATCCTT CTGTATCATT GTAAAT 26

WE CLAIM:

1. A chemical conjugate for treating a nerve cell related disorder, comprising: an inactive Clostridial neurotoxin having specificity for a target nerve cell; a drug or other bioactive molecule attached to said neurotoxin, wherein said neurotoxin retains its ability to enter said target nerve cell.

2. The chemical conjugate of Claim 1, wherein said Clostridial neurotoxin is selected from the group consisting of: tetanus toxin, botulinum toxin A, botulinum toxin B, botulinum toxin C, botulinum toxin D, botulinum toxin E, botulinum toxin F and botulinum toxin G.

3. The chemical conjugate of Claim 1, wherein said Clostridial neurotoxin has been inactivated by an amino acid change in its light chain.

4. The chemical conjugate of Claim 3, wherein said inactivated Clostridial neurotoxin is tetanus toxin having a modification of Glu^{234}, a botulinum toxin A having a modification at His^{227} and/or Glu^{224}, or a botulinum toxin other than botulinum toxin A having a modification at a site corresponding to His^{227} and/or Glu^{224} of botulinum toxin A.

5. The chemical conjugate of any of the foregoing claims for use in the treatment of a neuromuscular dysfunction in a mammal.

6. The chemical conjugate of Claim 5, for use in the treatment of a neuromuscular dysfunction relating to uncontrollable muscle spasms.

7. Use of the chemical conjugate of any of Claims 1-4 in the preparation of a medicament for treatment of a neuromuscular dysfunction in a mammal.

8. The use of Claim 7, wherein said neuromuscular dysfunction relates to uncontrollable muscle spasms.

9. The chemical conjugate of any one of Claims 1-4, wherein said drug is an active ingredient for treatment of botulism or tetanus.

10. The chemical conjugate of Claim 9, for use in the treatment of botulism or tetanus.

11. Use of the chemical conjugate of Claim 9 in the preparation of a medicament for treatment of botulism or tetanus in a mammal.

12. Use of an inactive Clostridial neurotoxin in the preparation of a medicament for treatment of acute botulinum toxin poisoning.

13. The use of Claim 12, wherein the Clostridial neurotoxin is used without conjugation to another drug.

14. Use of chemical conjugate comprising an active clostridial neurotoxin and a drug in the preparation of a medicament for treatment of focal dystonias, spasticities due to stroke or traumatic brain or spinal cord injury, blepharospasm, strabismus, cerebral palsy or back pain due to muscle spasms.

15. A method of treating a neuromuscular dysfunction in a mammal, comprising:

preparing a pharmaceutically active solution, wherein said solution comprises a Clostridial neurotoxin linked to a drug; and

introducing an effective quantity of said pharmaceutically active solution into a mammal.

16. The method of Claim 15, wherein said Clostridial neurotoxin is selected from the group consisting of: tetanus toxin, botulinum toxin A, botulinum toxin B, botulinum toxin C, botulinum toxin D, botulinum toxin E, botulinum toxin F and botulinum toxin G.

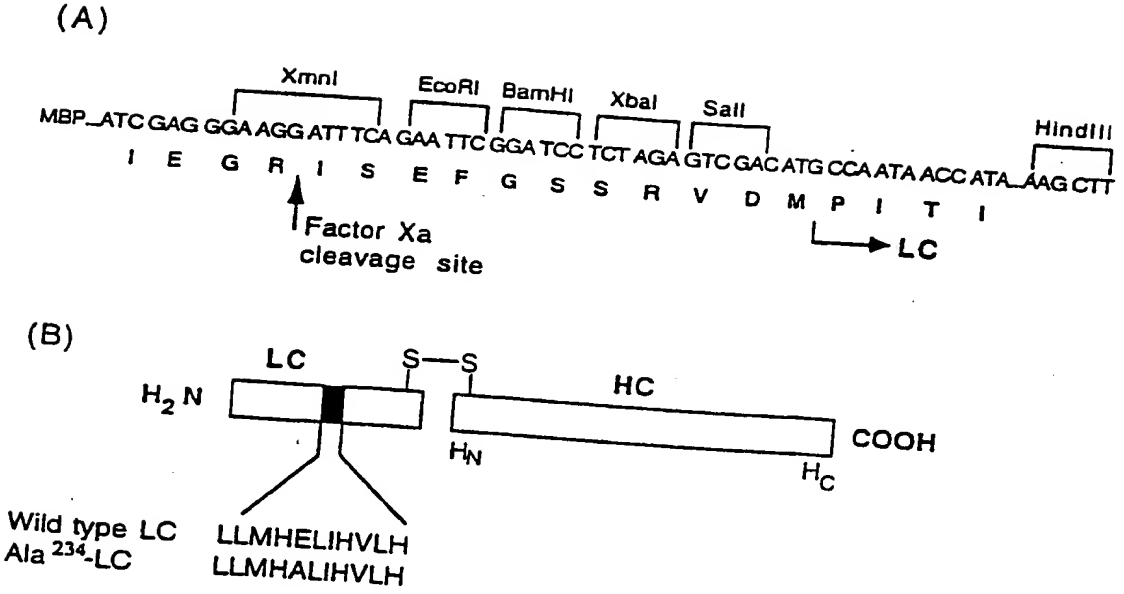
17. The method of Claim 15, wherein said Clostridial neurotoxin has been inactivated by an amino acid change in its light chain.

18. The method of Claim 15, wherein said drug inhibits neurotransmitter release.

19. The method of Claim 18, wherein said drug inhibits the activity of synaptobrevin.

20. The method of Claim 15, wherein said neuromuscular dysfunction relat s to uncontrollable muscle spasms.

FIG. 1


(A)
XmnI
EcoRI
BamHI
XbaI
SalI
HindIII
MBP-ATC GAG GGA AGG ATT TCA GAA TTC GGA TCC TCT AGA GTC GAC ATG CCA ATA ACC ATA-AAG CTT
I E G R I S E F G S S R V D M P I T I
Factor Xa cleavage site
LC
(B)
LC
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COOH
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H_C
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FIG.2

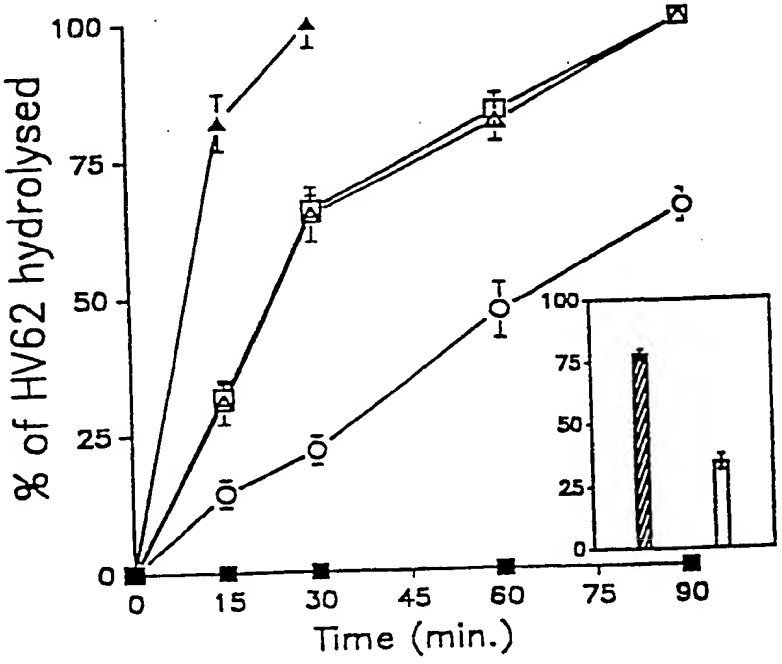

% of HV62 hydrolysed
100
75
50
25
0
0
15
30
45
60
75
90
Time (min.)
100
75
50
25
0

FIG. 3

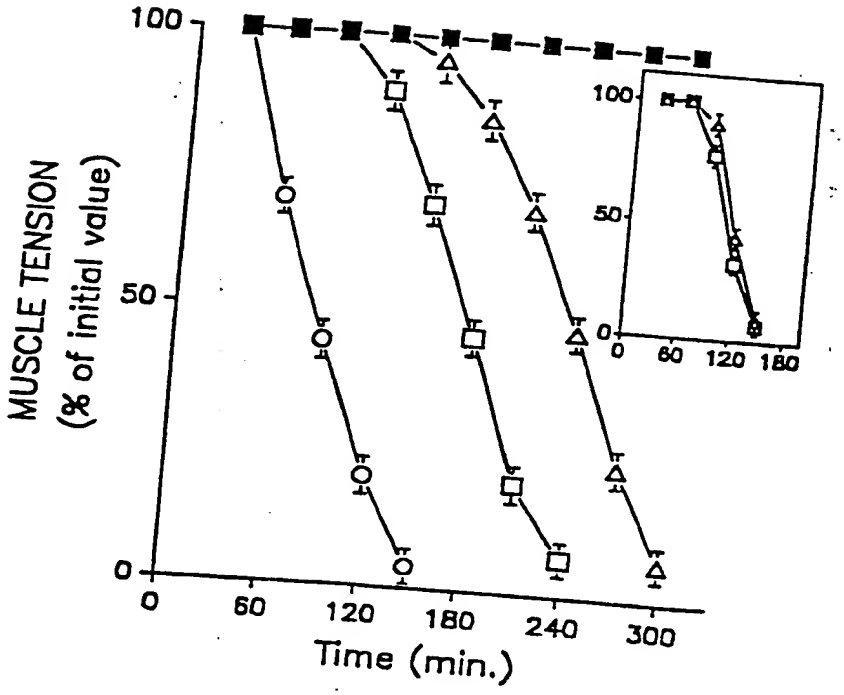
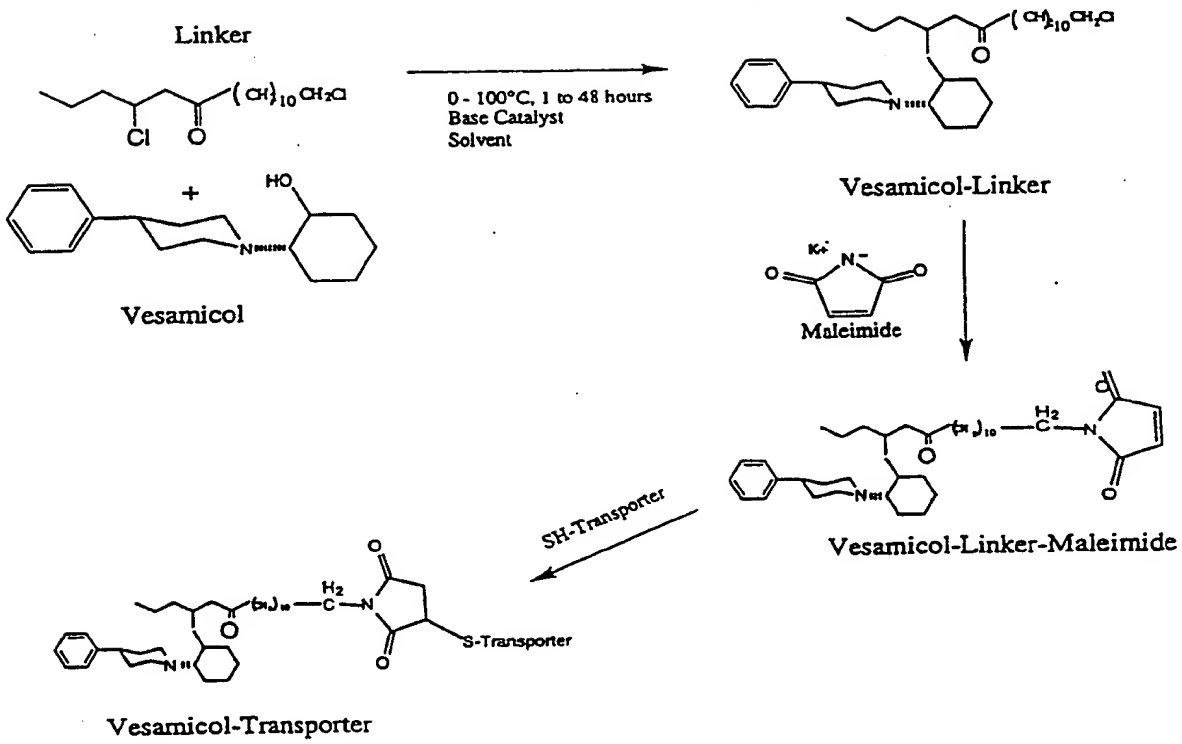

MUSCLE TENSION
(% of initial value)
100
50
0
0
60
120
180
240
300
Time (min.)
100
50
0
0
60
120
180

FIG. 4



Transporter = Inactive botulinum toxin

FIG. 5

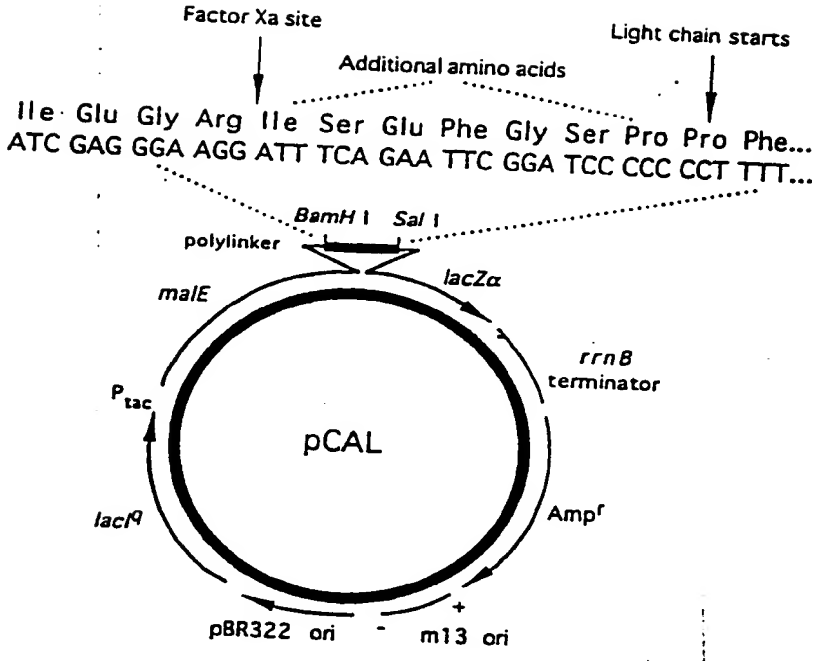

Factor Xa site
Light chain starts
Additional amino acids
Ile Glu Gly Arg Ile Ser Glu Phe Gly Ser Pro Pro Phe...
ATC GAG GGA AGG ATT TCA GAA TTC GGA TCC CCC CCT TTT...
BamH I
Sal I
polylinker
lacZα
malE
rrnB
terminator
Ptac
pCAL
lacIq
Ampr
pBR322 ori
m13 ori

FIG. 6

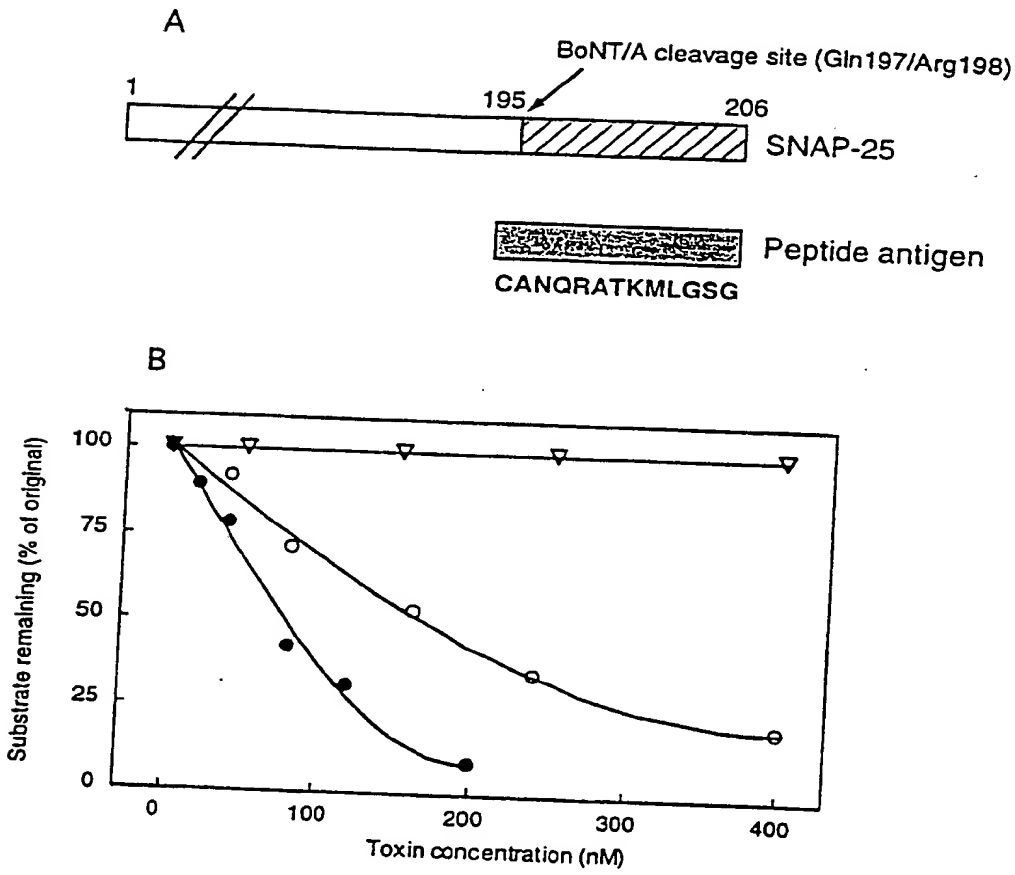

A
BoNT/A cleavage site (Gln197/Arg198)
1
195
206
SNAP-25
Peptide antigen
CANQRATKMLGSG
B
Substrate remaining (% of original)
100
75
50
25
0
0
100
200
300
400
Toxin concentration (nM)

FIG. 7

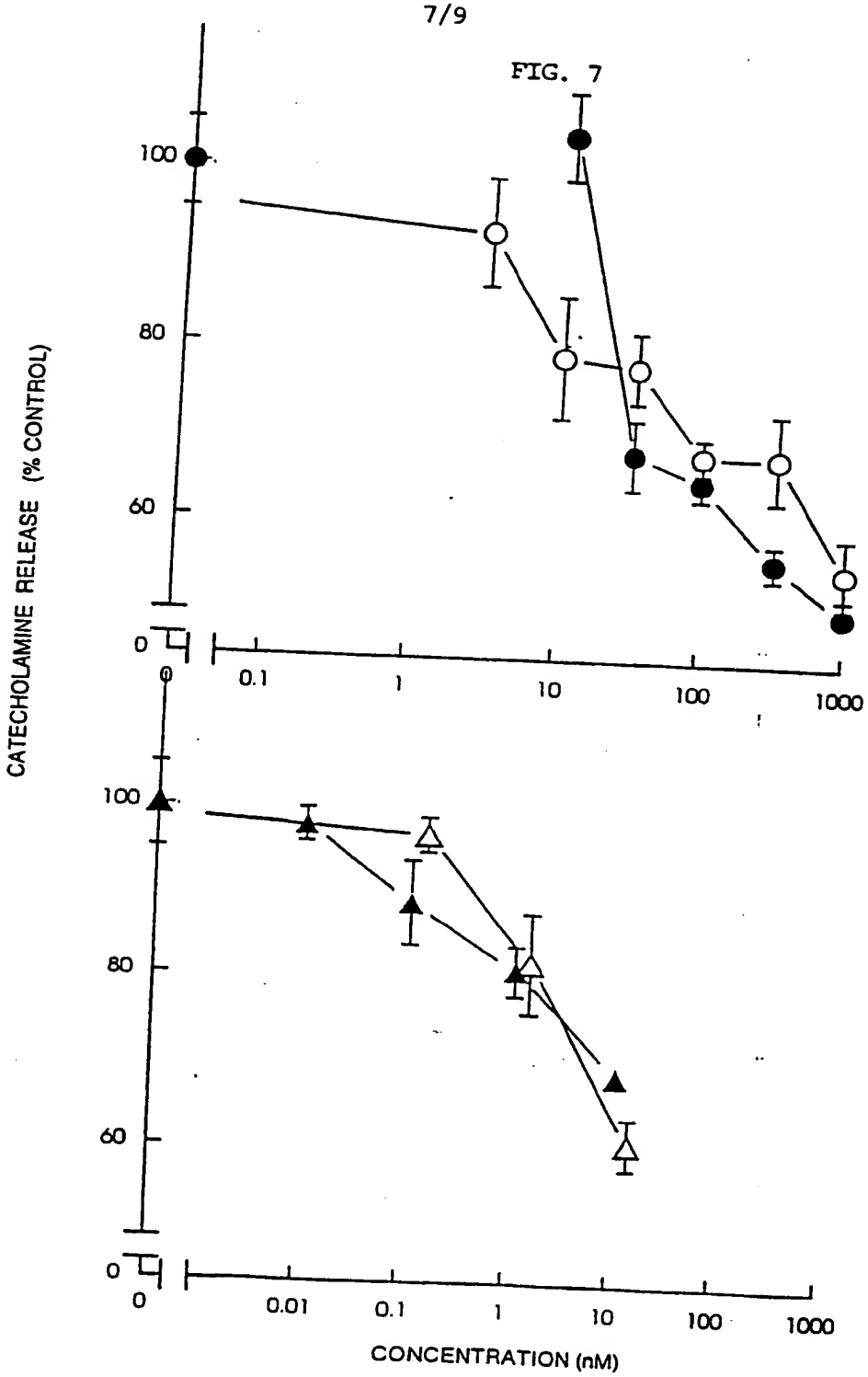
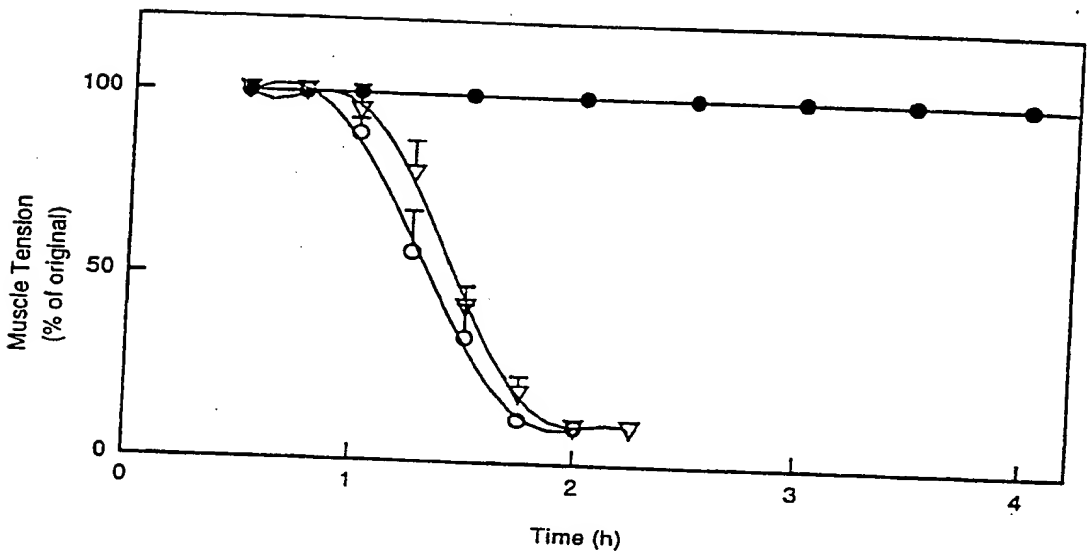

CATECHOLAMINE RELEASE (% CONTROL)
100
80
60
0
0
0.1
1
10
100
1000
100
80
60
0
0
0.01
0.1
1
10
100
1000
CONCENTRATION (nM)

FIG. 8



REPRESENTATION OF CONSTRUCTS USED TO PRODUCE MBP-BoNT/A L CHAIN DOUBLE MUTANT ❶ AND MBP-TeTx TRUNCATED L CHAIN-BONT/A L CHAIN DOUBLE MUTANT ❷

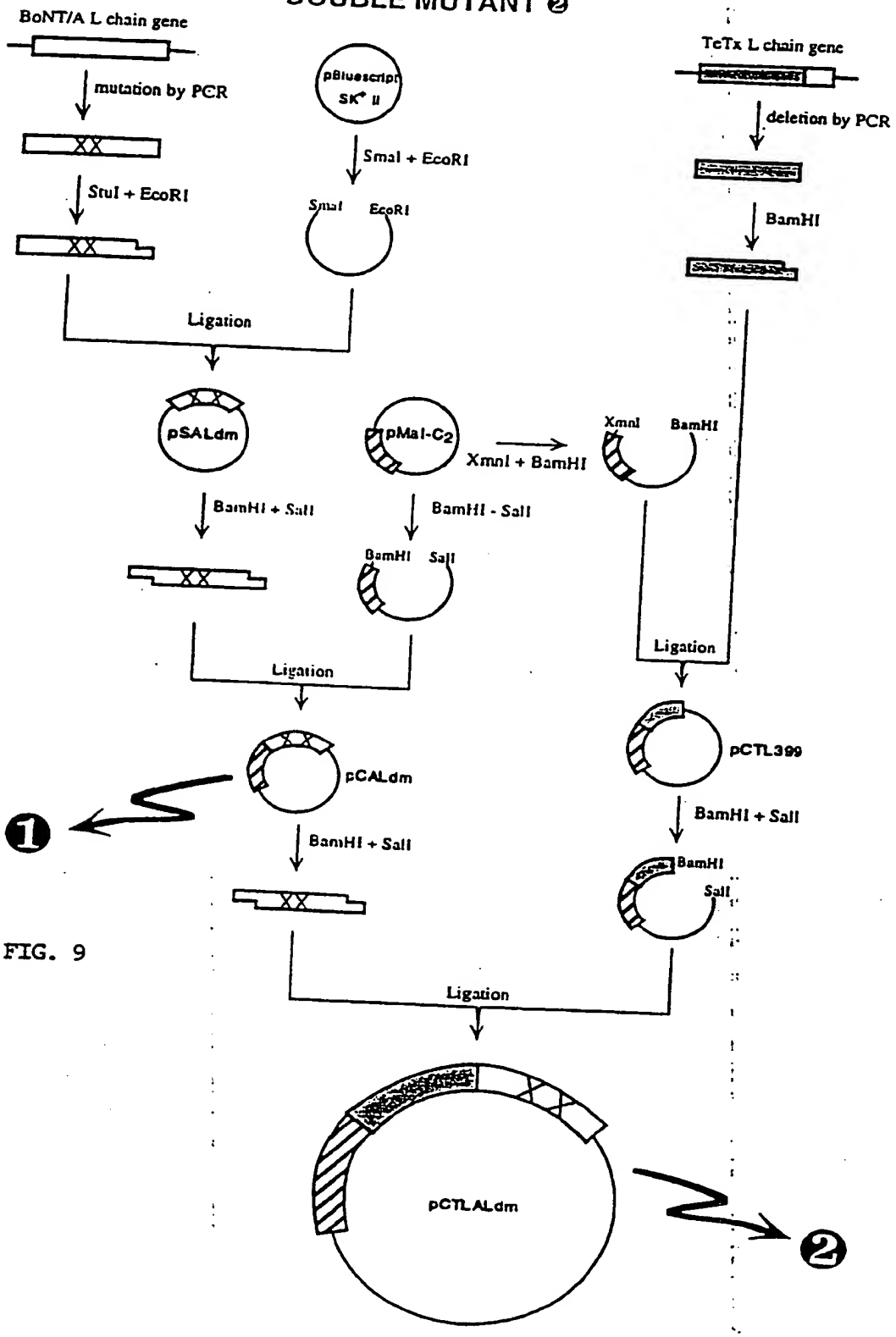


FIG. 9

INTERNATIONAL SEARCH REPORT

Inter ional Application No
PCT/GB 95/01253

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61K47/48

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CHEMICAL ABSTRACTS, vol. 122, no. 9, 27 February 1995 Columbus, Ohio, US; abstract no. 99061, FRAENKEL-CONRAT, H. L. 'A single mutation in the recombinant light chain of tetanus toxin abolishes its proteolytic activity and removes the toxicity seen after reconstitution with native heavy chain' see abstract	1-4,16, 17
X	& CHEMTRACTS: BIOCHEM. MOL. BIOL. (1994), 5(2), 176-7 CODEN: CMBIE5;ISSN: 1045-2680, 1994	13
	--- -/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 September 1995	13. 10 95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016	Berte, M

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 95/01253

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	WO-A-94 21300 (SPEYWOOD LAB LTD ;HEALTH LAB SERVICE BOARD (GB); NORTH JOHN ROBERT) 29 September 1994 see page 9, paragraph 2 see page 3, paragraph 4 - page 4 see page 5, paragraph 5 - page 6, paragraph 3 see page 9, paragraph 2 see page 13, paragraph 2 see page 20, paragraph 3; claim 14	1
X	US-A-4 594 336 (BIZZINI BERNARD) 10 June 1986 see column 6, line 31 - line 39; claims 1,3-6 see column 6, line 8-30	1-3, 5-11, 15-17,20
A	EP-A-0 254 905 (YEDA RES & DEV) 3 February 1988 see claims 1-3	1,2,16
X	WO-A-94 00487 (US ARMY) 6 January 1994 see page 1, line 7 - line 16 see page 3, line 4 - line 35 see page 4, paragraph 2 see page 8, line 5 - line 24; claims 1,15	1,2, 5-12, 15-17,20
P,Y	BIOCHEMISTRY (1994), 33(22), 7014-20 CODEN: BICHAW;ISSN: 0006-2960, 1994 LI, YAN ET AL 'A Single Mutation in the Recombinant Light Chain of Tetanus Toxin Abolishes Its Proteolytic Activity and Removes the Toxicity Seen after Reconstitution with Native Heavy Chain' see page 7014, column 1, paragraph 1 see page 7014, column 2, line 3, paragraph 2 see page 7019, column 2, paragraph 2	1-4,16, 17
A	FEBS LETT. (1993), 323(3), 218-22 CODEN: FEBLAL;ISSN: 0014-5793, June 1993 pages 218-222, FAIRWEATHER, NEIL F. ET AL 'Production of biologically active light chain of tetanus toxin in Escherichia coli. Evidence for the importance of the C-terminal 16 amino acids for full biological activity' see page 222, column 1, paragraph 2 - column 2, paragraph 1	12,13

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB95/01253

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
REMARK: Although claims 15-20 are directed to a method of treatment of (diagnostic method practised on) the human/animal body the search has been carried out and based on the alleged effects of the compound/composition.

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intc. ional Application No
PCT/GB 95/01253

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO-A-9421300	29-09-94	AU-B-	6217594	11-10-94
US-A-4594336	10-06-86	NONE		
EP-A-0254905	03-02-88	US-A-	5204097	20-04-93
WO-A-9400487	06-01-94	AU-B-	4545393	24-01-94

FIG. 1

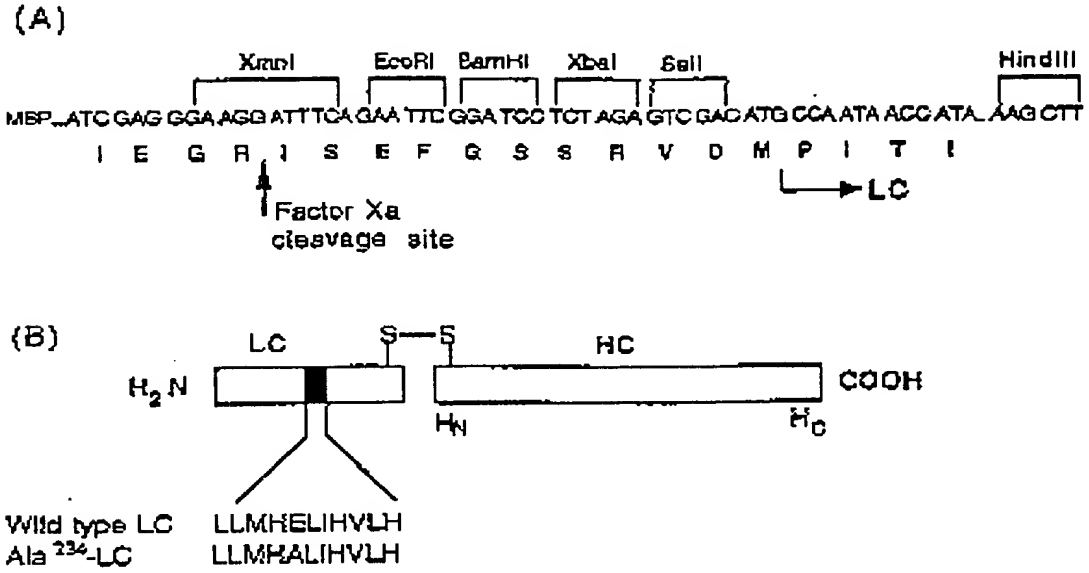

(A)
XmnI
EcoRI
BamHI
XbaI
SalI
HindIII
MBP-ATC GAG GGA AGG ATT TCA GAA TTC GGA TCC TCT AGA GTC GAC ATG CCA ATA ACC ATA-AAG CTT
I E G R I S E F G S S R V D M P I T I
Factor Xa cleavage site
LC
(B)
LC
S—S
HC
H_2N
COOH
H_N
H_C
Wild type LC LLMHELIHVLH
Ala 234-LC LLMHALIHVLH

FIG.2

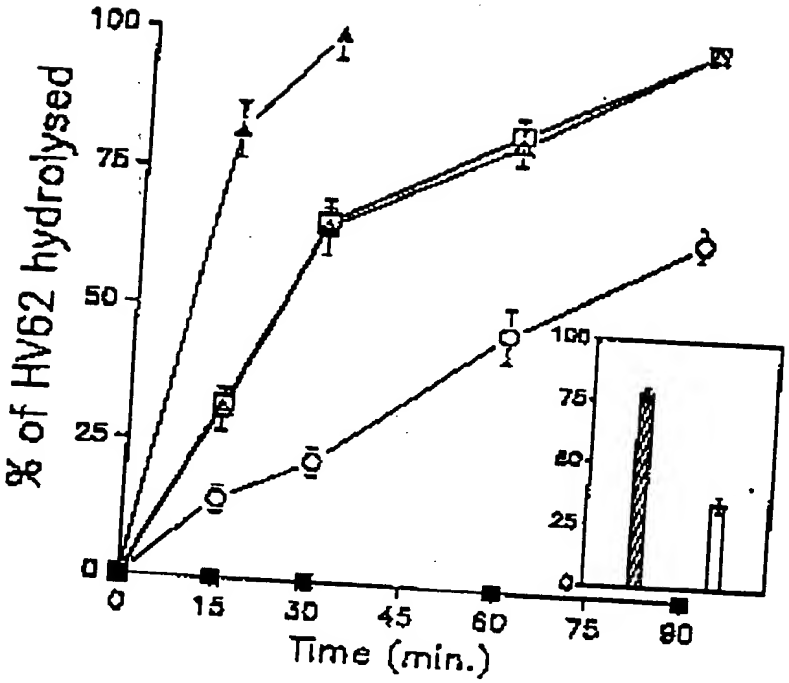


FIG. 3

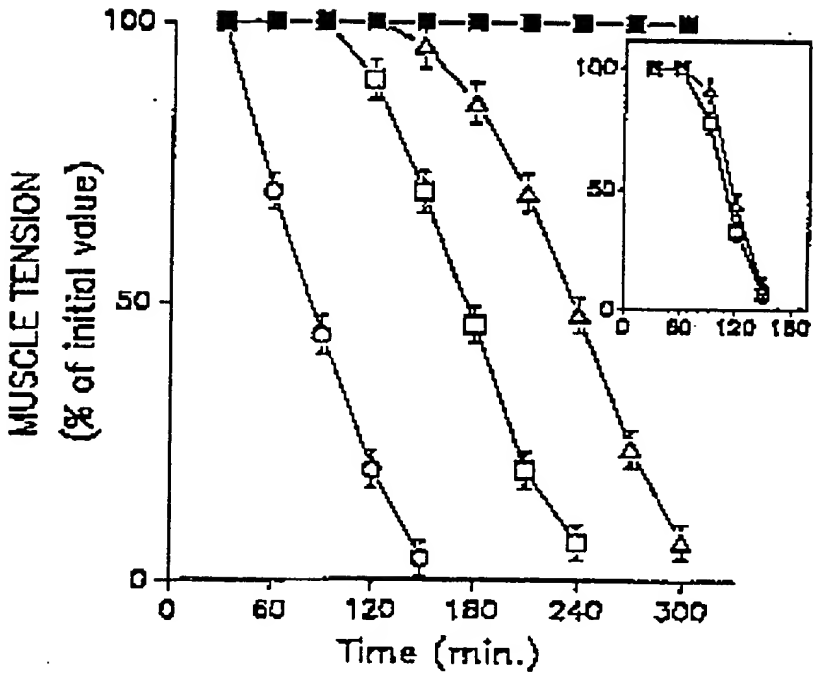
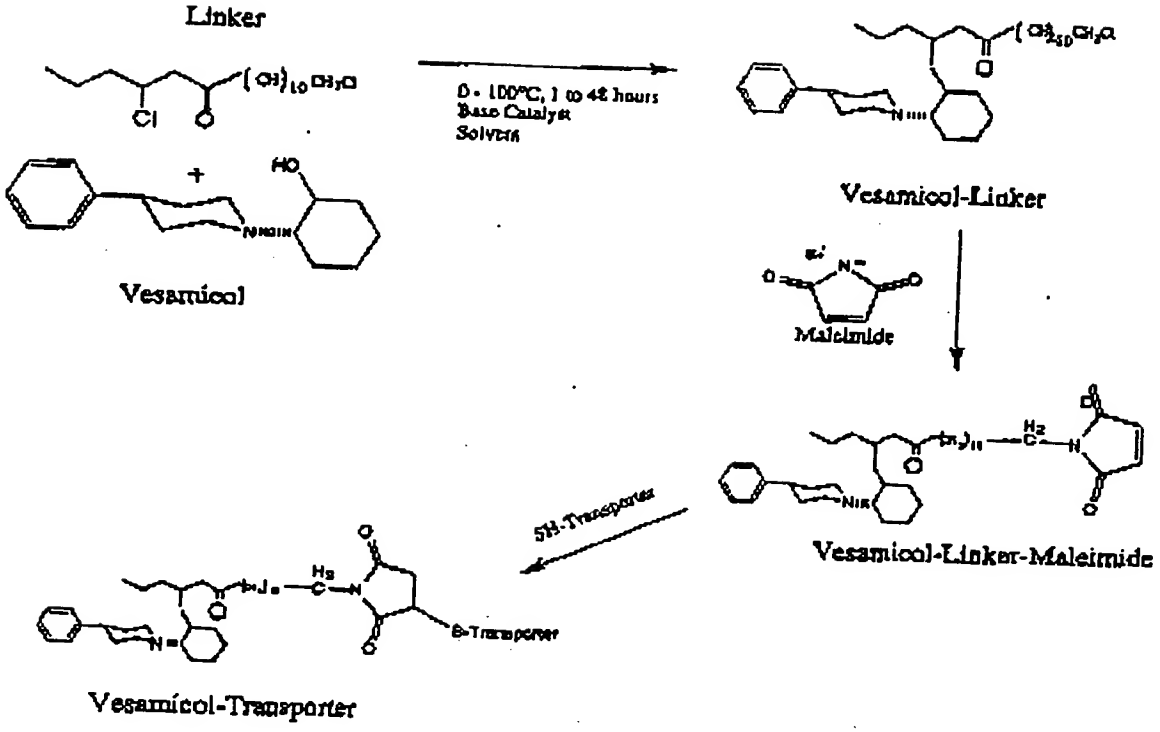

MUSCLE TENSION
(% of initial value)
100
50
0
0
60
120
180
240
300
Time (min.)
100
50
0
0
60
120
180

FIG. 4



Transporter = Ipsative botulinum toxin

FIG. 5

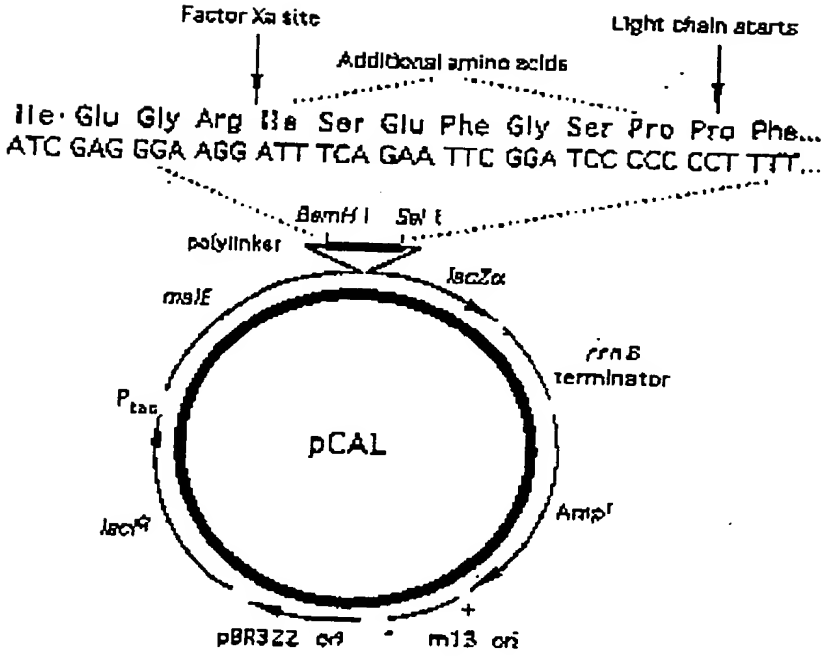


FIG. 6

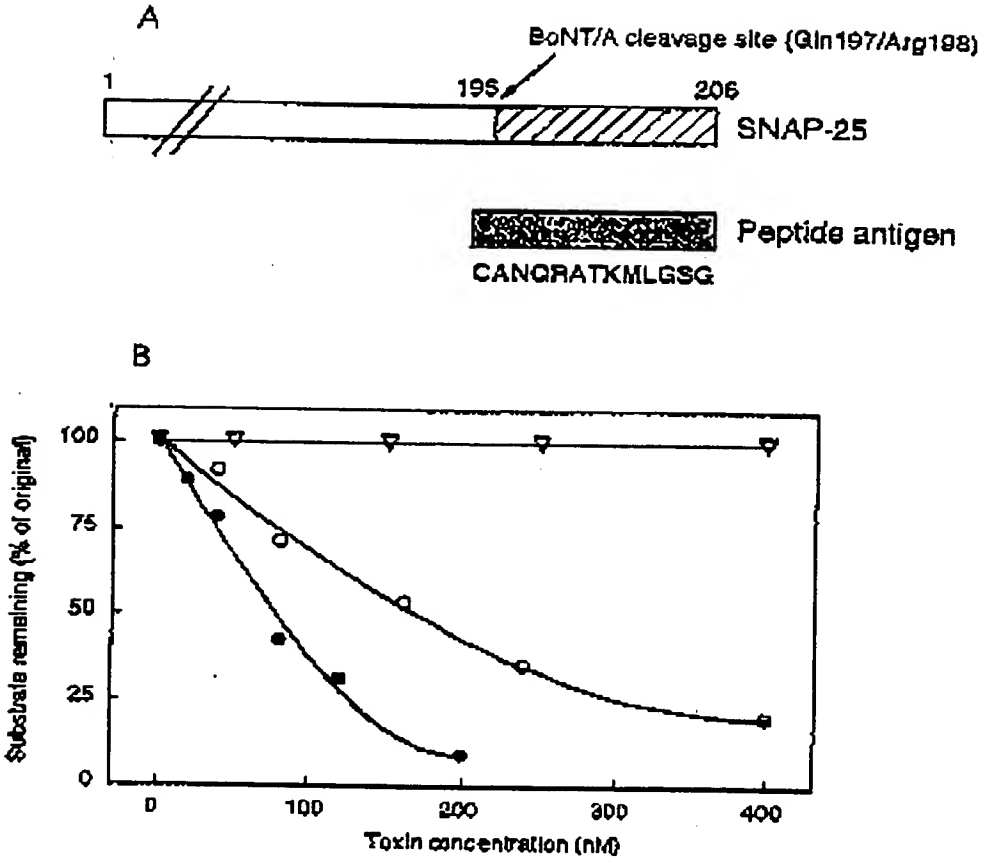

A
BoNT/A cleavage site (Gln197/Arg198)
1
195
206
SNAP-25
Peptide antigen
CANQRATKMLGSG
B
Substrate remaining (% of original)
100
75
50
25
0
0
100
200
300
400
Toxin concentration (nM)

FIG. 7

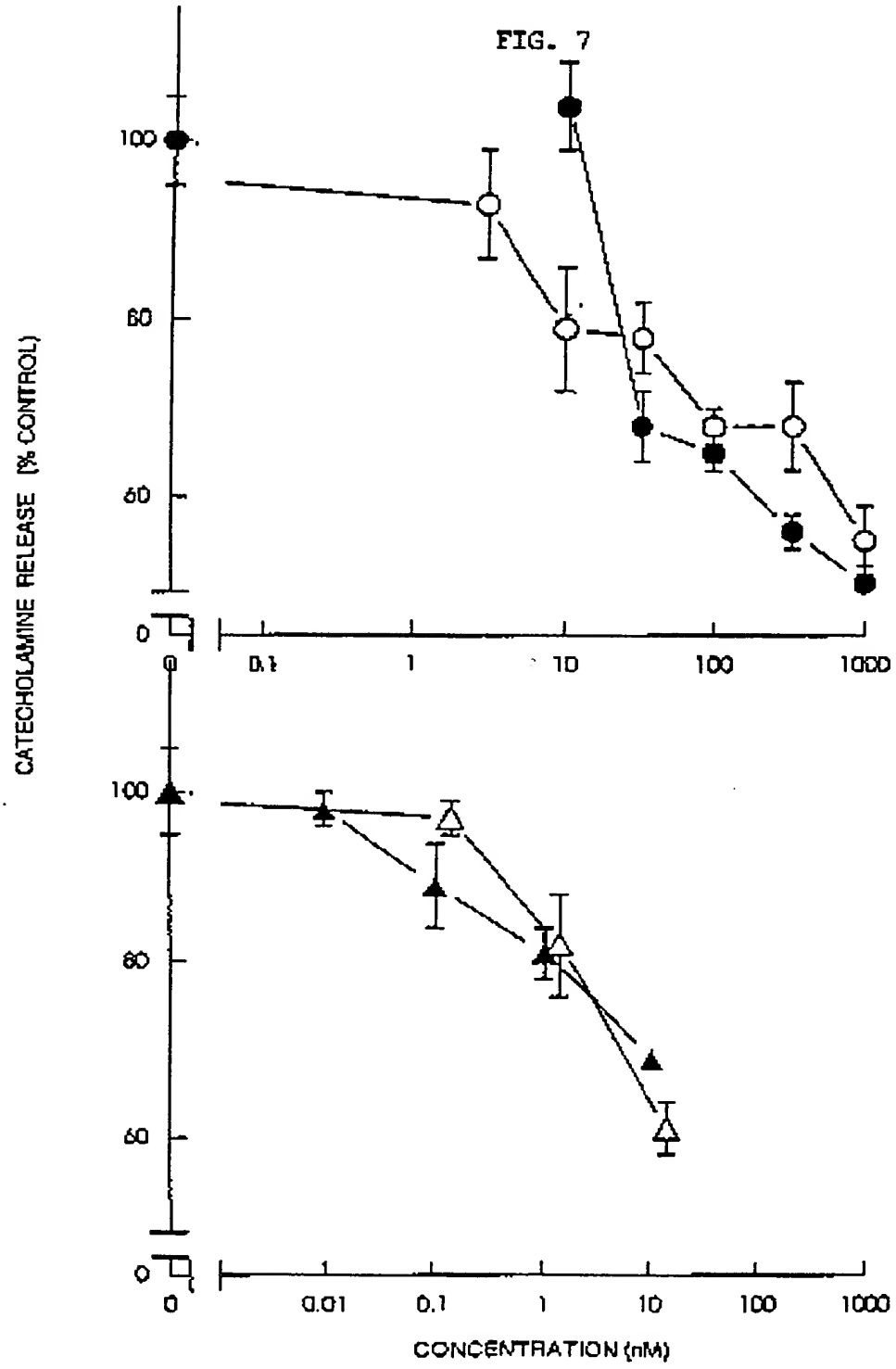
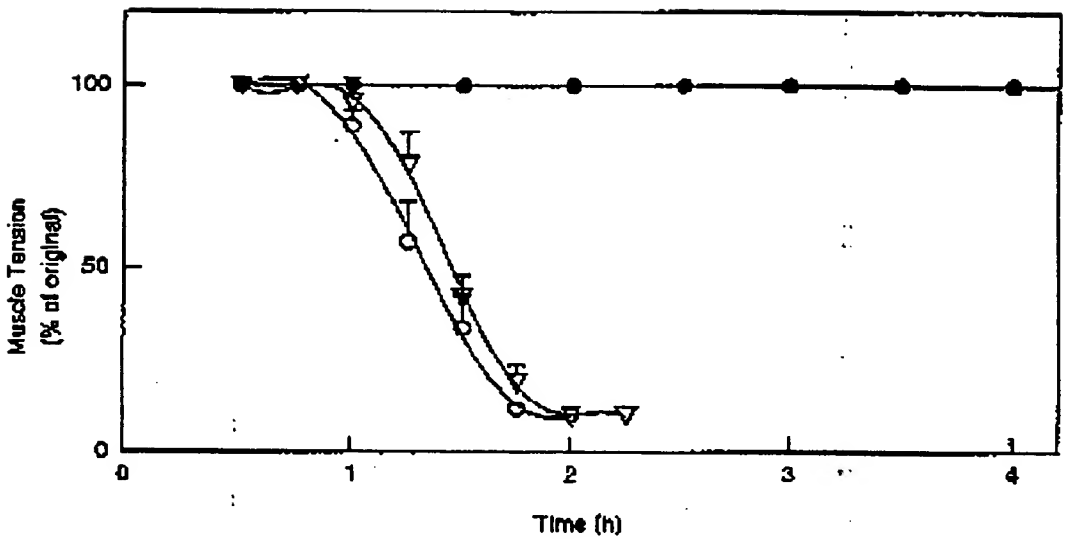

CATECHOLAMINE RELEASE (% CONTROL)
100
80
60
0
0
0.1
1
10
100
1000
100
80
60
0
0
0.01
0.1
1
10
100
1000
CONCENTRATION (nM)

FIG. 6



REPRESENTATION OF CONSTRUCTS USED TO PRODUCE MBP-BoNT/A L CHAIN DOUBLE MUTANT ❶ AND MBP-TeTx TRUNCATED L CHAIN-BONT/A L CHAIN DOUBLE MUTANT ❷

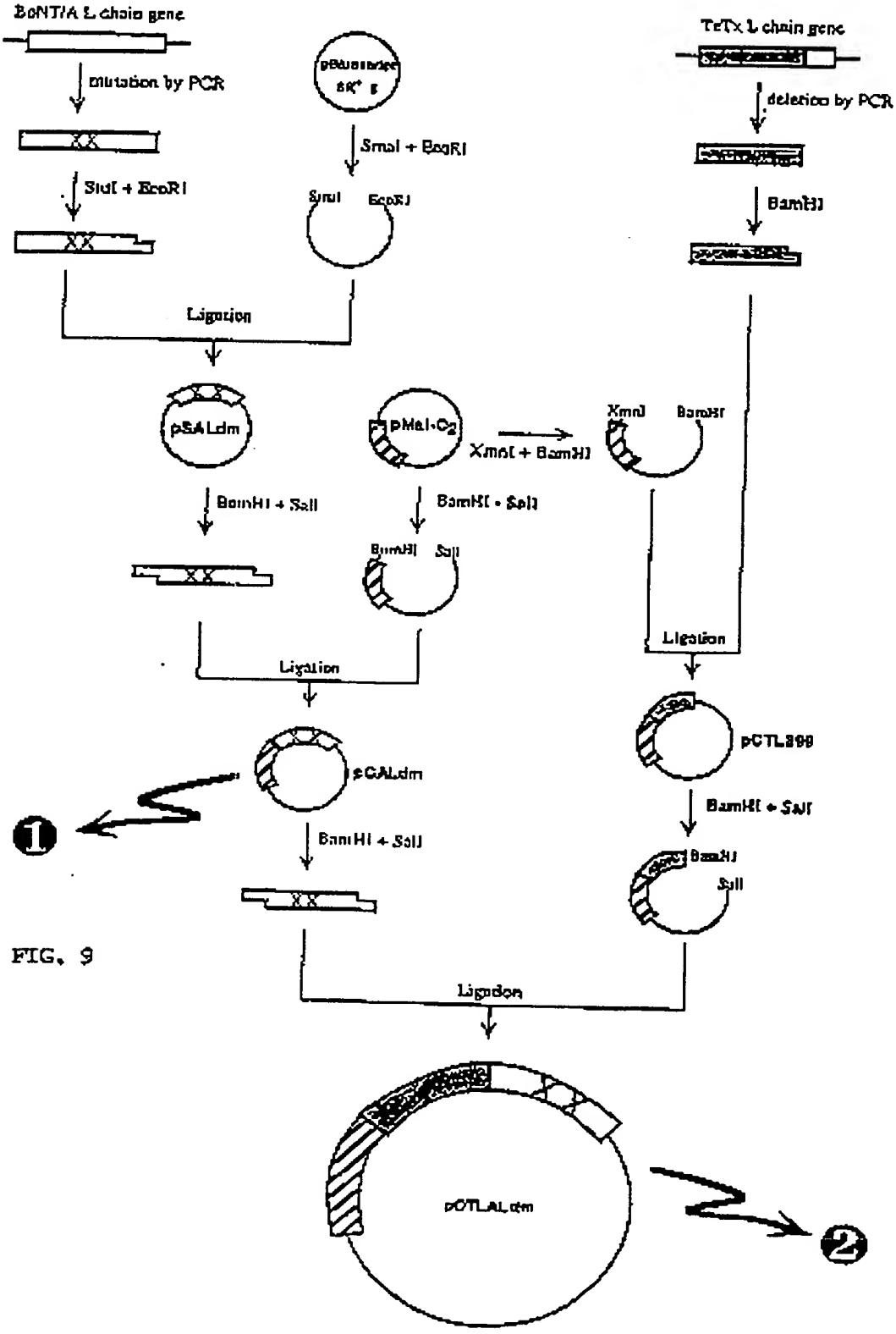


FIG. 9